FINAL REPORT

INTENSIVE RECONNAISSANCE SAMPLING OF GRAND CANYON TRIBUTARIES

GRAND CANYON NATIONAL PARK

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PURPOSE

This report provides a summary of findings associated with the study entitled" Intensive Reconnaissance Sampling of Grand Canyon Tributaries" which was funded by the Water Resources division for FY 93 and FY 94. The objective of the study was to inventory water quality characteristics of as many Arizona state-protected waters as possible at locations of potential impact. With this information, a long term monitoring network of sites representing a diversity of watersheds and potential upstream impacts could be developed. Such a network will be recommended in this report.

The main hypothesis discussed in the study plan was as follows: a subsample of water bodies selected to represent the diversity of watersheds draining into the Colorado River will be found to significantly differ in water quality composition by season, changing human use levels or discharge variations. The null hypothesis would be that water quality composition did not significantly differ.

For this study, all tributaries were sampled at the mouth where heavy recreational use can occur and where any impacts from upstream could be identified. It is recognized that some tributaries require more than one sampling point depending on input locations. It is also recognized that some constituents found in small amounts at the mouth may be of much higher, and more problematic concentrations upstream or vice versa. This study is simply an attempt at identifying special properties, potential problems or constituents of concern that may warrant more intensive sampling along the length of the tributary. By addressing the hypothesis it can be determined if identified properties, problems or concerns are directly related to discharge, season or human use levels. And as mentioned above, this study has provided the opportunity to gather enough information to make sound recommendations as to the frequencies that tributaries should be sampled in the future based on these findings.

SAMPLING COMPLETED

Ten sampling sessions took place beginning in May, 1992. Three spring sessions, three summer sessions, three fall sessions and one winter session were completed with the funding provided. The funding covered the field sampling/analysis, river trip support and part of the laboratory analyses procured for the study. Some laboratory expenses, all salaries and data compilation were covered with park base funding.

Some assistance was provided from the Arizona Department of Environmental Quality in the analysis of aquatic invertebrate species composition along sixteen of the 24 tributaries in the study. This part of the study will be discussed briefly, but not completely since identification and analysis by the state is

TABLE 1. FINAL REPORT - WATER RESOURCE SAMPLING SITES
INTENSIVE RECONNAISSANCE STUDY

LOCATION	SPRING 92	SUMMER 92	FALL 92	SPRING 93	SUMMER 93	FALL 93	COMMENT
TAPEATS	X(G)	X(G),B,A	X(G),B	X,B	X,B,A	X,B	CORE
KANAB	X(G)	X(U),B,A	X(U),B	X(G),B	X,B,A	X(I),B	CORE
HAVASU	X(G)	X(U),B,A	X(U),B	X(G),B	X,B	X(I),B	CORE
VASEYS	X(G)	B,A	X,B	X,B	X,B	X,B	CORE
BRI.ANGEL		X,B,A	X,B	X,B	X,B,A	X,B	CORE
PARIA		X,B,A	X,B	X,B	X,B	X,B	CORE
LCR		X(U),B	X(G),B	X(G),B	X,B	X(I),B	CORE
NANKO-WEAP		X(G),B,A	X,B		X,B,A	X,B	CORE
LAVA CH.		X(G)	X(G)		X	X	CORE
HERMIT		X(G),B,A	X(G),B		X,B,A	X,B	CORE
CRYSTAL		X(G)	X(G)		X,A	X,B	CORE
SHINUMO		X,B	X,B		X,B	X,B	CORE
ROYAL ARCH		X,B,A	X,B		X,B,A	X,B	CORE
MATKATA-MIBA		X,B,A	X,B		X,B	X,B	
NATIONAL		X(G),B	X(G),B		X,B,A	X,B	CORE
WARM SP		B	B		X,B	X,B	NO SPRING
SPRING		X,A	X		X(G),B,A	X,B	CORE
3 SPGS.		B	B		X(G),B,A	X,B	
PUMPKIN		X(U)	X(U)				NO SPR.
STONE		B	B		B	B	
MON. CR*		B	B		B		NO SPR.
CLEAR		B	B		B	X,B	
DEER		B	B		B	X,B	
KWAGUNT						N,B	
SADDLE			B		B	N,B	

X = FULL SUITE OF CHEMISTRY COMPLETED (SEE TABLE 2)
B = BACTERIA ANALYSES DONE ALSO
A = AQUATIC INVERTEBRATES COLLECTED ALSO
G = GROSS ALPHA/GROSS BETA RADIONUCLIDES ALSO
U = TOTAL URANIUM ALSO
I = RADIOISOTOPES ALSO, N = NUTRIENTS ONLY
CORE = CORE SAMPLE SITE (SAMPLED AT LEAST 8 TIMES)
SPRING/SPR. = SITE WAS NOT SAMPLED FOR SPRING RUNOFF; * = MONUMENT CREEK

TABLE 1. FINAL REPORT - WATER RESOURCE SAMPLING SITES
INTENSIVE RECONNAISSANCE STUDY - CONTINUED

LOCATION	WINTER 94	SPRING 94	SUMMER 94	FALL 94			COMMENT
TAPEATS	X(G),B		X,B,A	X,B			CORE
KANAB	X(G),B		X,B,A	X,B			CORE
HAVASU	X(G),B		X,B	X,B			CORE
VASEYS	X(G),B		X,B				CORE
BRI.ANGEL	X(G),B		X,B,A	X,B			CORE
PARIA	X(G)			X			CORE
LCR	X,B		X,B	X,B			CORE
NANKO-WEAP	X,B	X,B	X,B	X,B			CORE
LAVA CH.	X,B	X,B		X,B			CORE
HERMIT	X,(G),B	X,B	X,B,A	X,B			CORE
CRYSTAL	X,B	X,B	X,B,A	X,B			CORE
SHINUMO	X,(G),B	X,B	X,B	X,B			CORE
ROYAL ARCH	X,(G),B	X,B	X,B,A	B			CORE
MATKATA -MIBA		X,B					
NATIONAL	X(G),B	X,B	X,B,A	X,B			CORE
WARM SP			X,B	X,B			NO SPRING
SPRING	X(G),B	X,B	X,B,A	X,B			CORE
3 SPGS.		X	X,B,A	X			
PUMPKIN							NO SPR.
STONE		X,B	X,B	X,B			
MON. CR*				X,B			NO SPR.
CLEAR		X,B	X,B	X,B			
DEER		X,B	X,B**,A	X,B			
KWAGUNT		X,B	X,B	X,B			
SADDLE		X,B					

X = FULL SUITE OF CHEMISTRY COMPLETED (SEE TABLE 2)
B = BACTERIA ANALYSES DONE ALSO
A = AQUATIC INVERTEBRATES COLLECTED ALSO
G = GROSS ALPHA/GROSS BETA RADIONUCLIDES ALSO
CORE = CORE SAMPLE SITE (SAMPLED AT LEAST 8 TIMES)
SPRING/SPR. = SITE HAS NOT HAD SPRING RUNOFF SAMPLED
* = MONUMENT CREEK, ** = TIME SERIES DONE FOR BACTERIA

TABLE 2. PARAMETERS MEASURED DURING INTENSIVE RECONNAISSANCE STUDY

<u>Field Measurements done at each Site</u>
Discharge (cubic feet per second)
Conductivity (microseimens)
pH
Dissolved oxygen (milligrams/liter, mg/l)
Alkalinity (mg/l as CaCo3)
Turbidity (NTUs)
Air Temperature (centrigrade)
Water Temperature (centigrade)

<u>Bacteria analyses done for Most Sites</u>
Fecal coliform
Fecal streptococcus

<u>Chemical Analyses done for each Site (mg/l)</u>
Total Dissolved Solids
Total Suspended Solids
Chloride
Fluoride
Ammonia as N
NO2/NO3-N, Total
Sulfate
Kjeldahl Nitrogen
Total Phosphorus
Potassium
Magnesium
Calcium
Sodium
Silver
Arsenic
Beryllium
Cadmium
Chromium
Copper
Mercury
Nickel
Lead
Antimony
Selenium
Thallium
Zinc

<u>Radionuclides done at Selected Sites</u>

Gross alpha/gross beta	Total Uranium

<u>Radioisotopes done at Selected Sites</u>

Uranium 234	Uranium 235	Uranium 238
Radium 226	Radium 228	
Thorium 228	Thorium 230	Thorium 232

still awaiting completion. The state also provided some of the initial water quality laboratory analysis funding in 1992.

In a separate, but related study, the University of Nevada, Las Vegas performed intensive sampling along four tributaries in the vicinity of their spring outlets to determine groundwater pathways (see progress report for a full description of what was sampled). This study has been completed and the final thesis will be available to the Park by April, 1995. The information will compliment this reconnaissance study by providing water constituent composition for these tributaries further upstream.

Table 1 provides a list of the twenty-four tributaries sampled in this study; when each tributary was sampled and what was sampled each time. In all instances, field parameters (temperature, pH, conductivity, dissolved oxygen, turbidity and discharge) were sampled. Fourteen 'core' tributaries: Tapeats, Kanab, Havasu, Vaseys, Bright Angel, Nankoweap, Lava Chuar, Hermit, Crystal, Shinumo, Royal Arch, National and Spring Canyon creeks and the Paria and Little Colorado rivers were sampled for intensive laboratory analysis at least seven times and during all four seasons. As can be seen in the table, 1994 was used to expand the number of core tributaries and to complete a winter sampling session. Priorities for which tributaries should be sampled more were based on types of use, types of impacts and whether another tributary of similar chemistry was a 'core' tributary.

Table 2 provides a list of the parameters measured. All chemical and radionuclide/radio-isotope analyses were performed by Analytical Technologies of Phoenix, Arizona. An estimated $60,000 of Water Resources, Park base and Arizona Dept. of Environmental Quality funds were used for this purpose (completed invoices should be on file in the Park procurement office).

DATABASE COMPLETION AND ANALYSES

The amount of data collected for this study was enormous. All data has been entered in the database (using DBase III+ software) discussed in the progress report (another copy of that appendix will be attached to this report). This database should hopefully merge well into the database being developed by the Water Resources division. A program was also developed by the Park hydrologist using EXCEL software to automatically calculate discharges while in the field. This was extremely helpful in reducing error. All data was then transferred over to EXCEL for graphing purposes to determine preliminary relationships that may be of interest to analyze in more detail. These preliminary relationships will be the primary focus of discussion for this report.

PRELIMINARY RESULTS

These results are discussed as preliminary in this report because there is a need for more detailed analysis that could not be completed at this time. The amount of data gathered and the lack of staff to input the data has required more time than available for this report to complete final analyses. Also, the statistical packages available at Grand Canyon are not of the kind needed for assessing water quality trends based on seasonality. A highly recommended software package called WQSTAT should be procured by the Park to accomplish the statistics necessary.

There will also be a need for multivariate analyses when the aquatic invertebrate data becomes available. This would help to determine relationships between invertebrate species composition and water quality or quantity variables.

Trends in Bacteria Concentrations

Identifying trends in bacteria levels is extremely important considering the health problems that can occur along the Colorado River corridor. In the high use season of 1994, a river illness was reported during the month of July. A total of 108 cases were reported with symptoms including abdominal cramps, nausea, vomiting, diarrhea and extreme fatigue. The duration of the illness ran from 2 to 3 days with 92.5% occurring below Phantom Ranch (the lower half of most river trips). The cause of this illness is yet unknown. It could be attributed to water-borne disease, which could have been caused by unsanitary food preparation or improper human waste disposal. It could also have been caused by improper treatment of drinking water from the river or tributaries which could have been contaminated with fecal matter. The question will not be answered until next summer when a noted authority on water-borne diseases will sample for a multitude of potential causes along the entire length of the river corridor.

Identifying trends in bacteria concentrations is extremely difficult to do accurately. This is because bacteria can be difficult to capture in a sample if it is tied to sediments and because bacteria levels tend to fluctuate greatly depending upon discharge or amount of use at the time of sampling. This provides high variability which, in turn, makes for difficulty in obtaining statistically valid results.

Two species of fecal bacteria were sampled. Fecal coliform is the species most associated with human fecal contamination. Fecal streptococcus (written as fecal strep. for this report) is more associated with wildlife fecal contamination. The ratio of 4:1 fecal strep. to fecal coliform has been shown to indicate that bacteria is probably of wildlife origin.

Brickler and Tunnicliff (1980) concluded from a bacteriological study of the Colorado River over two summers in the 1970s that bacteria levels were highly dependent upon turbidity of the water. The highest bacteria levels were found in bottom sediments which meant that when sediments were stirred up due to flood, bacteria levels in the water column increased. Brickler and Tunnicliff found this trend mostly in the Colorado River and the few tributaries sampled. They also found that when the river or tributaries were not in flood, bacteria levels should be negligible unless bottom sediments were stirred up significantly through water play.

Results from this present study tend to agree with the general conclusions stated by Brickler and Tunnicliff and provide more details on how bacteria levels may fluctuate and that water levels did not necessarily need to be in flood or in high use to find higher levels of bacteria.

Essentially, conclusions can be discussed in two separate result categories. First of all, some tributaries did show a positive relationship between high turbidity and/or discharge levels and high levels of bacteria. These tributaries were the Little Colorado River, Tapeats Creek, Havasu Creek, Paria River, Kanab Creek, Saddle Creek, Deer Creek, Kwagunt and Nankoweap Creeks.

Contrary to previous studies, the Little Colorado river never produced high levels of either Fecal coliform or Fecal strep. Bacteria concentrations found of both species did tend to be higher when turbidity was higher, though, especially during flooding. It should be noted that discharge measurements were difficult to perform due to deep channels, high winds and high conductivities that seemed to effect the velocity meter. Since studies previous to this one did capture high amounts of bacteria, it can be concluded that such levels can be possible again, but not on a consistent or predictable basis. Also, it is worth noting, that the majority of flow at the Little Colorado River mouth can be attributed to Blue Springs (about 15 miles upstream). Therefore, it can be postulated that Blue Springs provides a relatively bacteria-free water source that is usually only contaminated significantly during floods coming from upstream of the springs.

Tapeats Creek never exhibited high levels of bacteria, either, except on one occasion where flooding due to heavy rains brought an excess of 150 cubic feet per second (cfs) down the channel. Tapeats creek usually ranges in discharge from 50 to 70 cfs. Turbidity was also at its highest during this time as well. Fecal coliform levels could have exceeded state standards at some time during that flood. The state standard for a single sample is 800 Fecal coliform colonies per 100 ml; 600 were counted for that sample. This situation occurred during the fall season. High bacteria was not found during spring run-off events which could lead to the postulation that heavy flows in the fall may bring more bacteria due to the heavy summer and fall hiking use along the creek upstream.

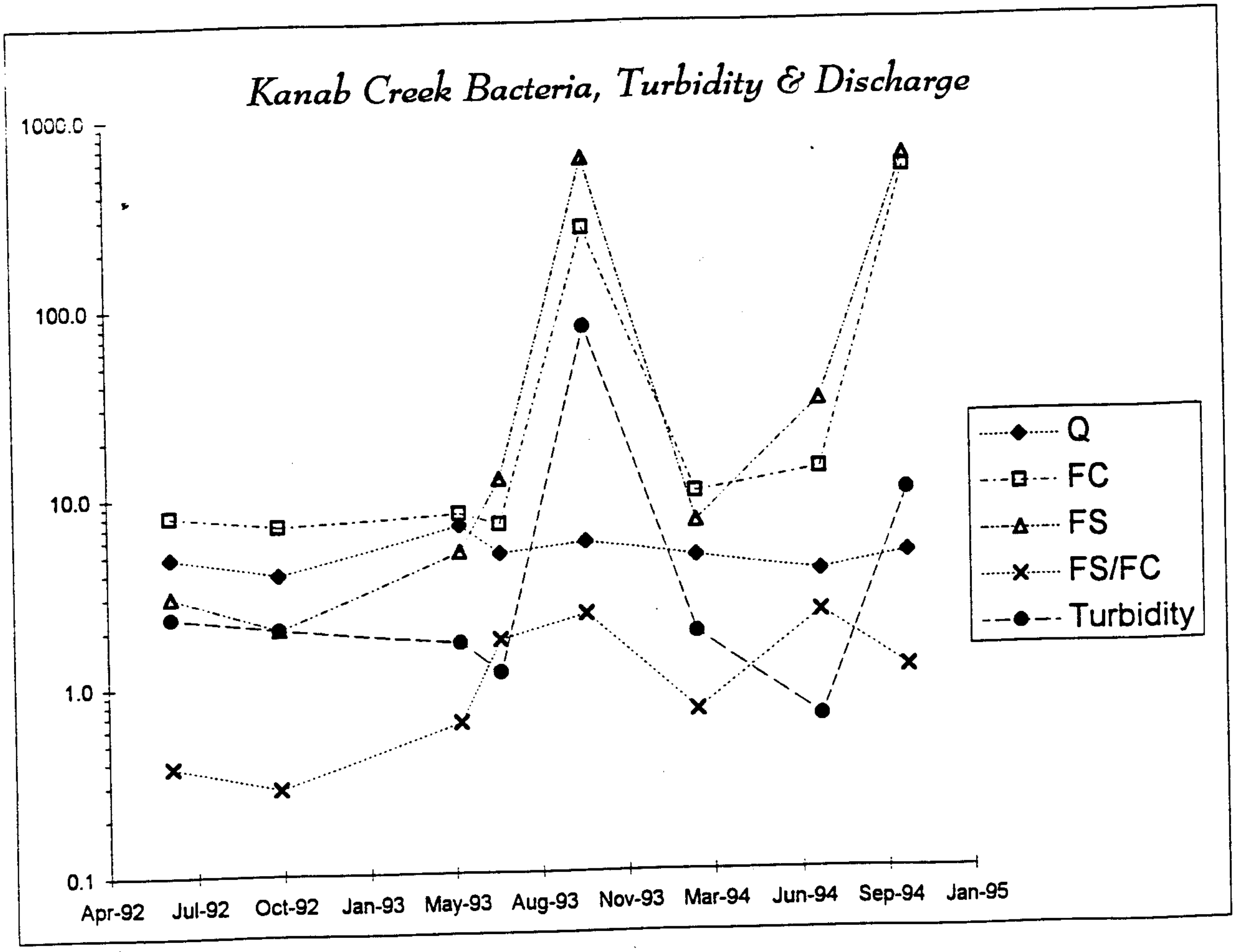
Bacteria levels at Havasu Creek tend to follow fluctuations in turbidity more than fluctuations in discharge. Throughout the sampling sessions, Havasu discharge was fairly consistent with no flooding events. Turbidity did fluctuate more than the discharge, though. Both fecal coliform and fecal strep. levels were not high during any sampling period, although they did increase during higher turbidity. It should be noted that it was more difficult to count bacteria colonies at Havasu during high turbidity, though, which means there is a chance that bacteria levels could be higher. It is recommended that a bacteria sample be taken when the creek is in flood to provide information on how background levels increase.

On the Paria River, which consistently flows extremely turbid, fecal coliform levels increased with turbidity, but fecal strep. tended to increase when turbidity (and discharge) were less. The ratio between the two species is high, which means that the levels are probably related to wildlife contamination. This is most likely the case since the highly turbid water of the Paria is not aesthetically pleasing and does not attract water play. Again, colonies were difficult to count because of the turbid water.

Kanab Creek (see Figure 1) bacteria concentrations followed increases in turbidity closely, but not necessarily discharge. Discharge was fairly consistent seasonally except for spring 1992 when higher discharge was measured. Unfortunately, neither turbidity or bacteria were collected at that time, although it can be postulated that due to the significant increase in discharge (six-fold), at least fecal strep. bacteria concentrations were probably high. Both fall samplings from 1993 and 1994 show high turbidity and the highest fecal coliform counts. The ratio shows that these counts could have originated from human sources. The high turbidities and low discharge mean that recent rainfall contributed. The bacteria level probably came not from water play, but from surface run-off in areas of past high recreation use.

Both Nankoweap and Kwagunt creeks were found to have high fecal strep. counts during events of high turbidity (not high discharge, though) with the source most likely wildlife. Fecal coliform counts were very low for both these creeks.

Saddle and Deer creeks were found to have high fecal coliform counts during higher turbidity levels. This could be related to the time that turbidity was measured. In the case of Saddle Canyon, fecal coliform counts were close to state health standards (600 colonies per 100 ml) probably because of a storm taking place directly upstream (no visitation was taking place). As with Kanab Creek, rainfall probably contributed to surface



Kanab Creek Bacteria, Turbidity & Discharge
1000.0
100.0
10.0
1.0
0.1
Apr-92
Jul-92
Oct-92
Jan-93
May-93
Aug-93
Nov-93
Mar-94
Jun-94
Sep-94
Jan-95
Q
FC
FS
FS/FC
Turbidity

run-off of bacteria from past high use (Saddle is a very popular spot for water play due to its waterfalls).

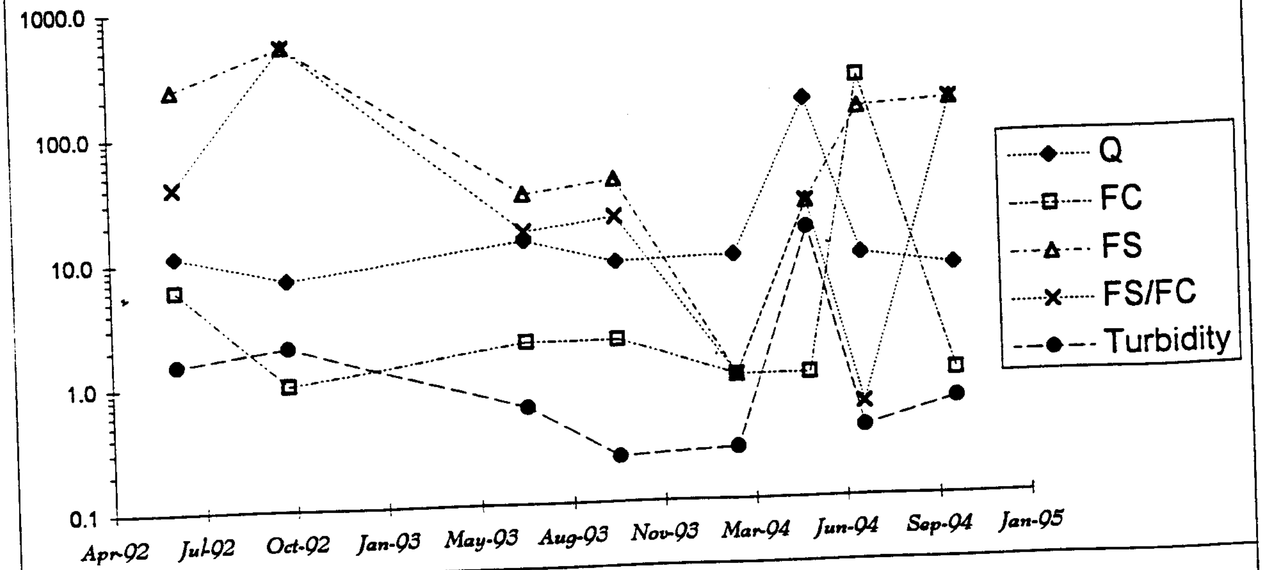
In the case of Deer Creek, turbidity was more likely to be related to water play taking place at the time of sampling. In the summer of 1994, this idea was tested by performing a 24 hour time series study where bacteria were sampled every hour at the mouth of Deer creek (where most human use was taking place) and upstream of most human water play above the Deer Creek narrows. Turbidity was visually estimated (i.e. not measured quantitatively) and the number of people both in the water and on shore were recorded throughout the 24 hour period. It was found that during active water use (in this case, wading at the mouth), turbidity increased dramatically and fecal coliform counts were also high (387 colonies per 100 ml in one instance and 363 colonies per 100 ml in another). Within an hour of non-use, turbidity disappeared as bottom sediments settled and fecal coliform counts dropped to almost zero at the mouth. In another instance, high use upstream (swimming in what is known as the 'spa' at Deer Creek narrows) did not elicit high fecal coliform counts at the mouth until one hour later (with 1437 colonies per 100 ml; a definite exceedance of a single sample health standards).

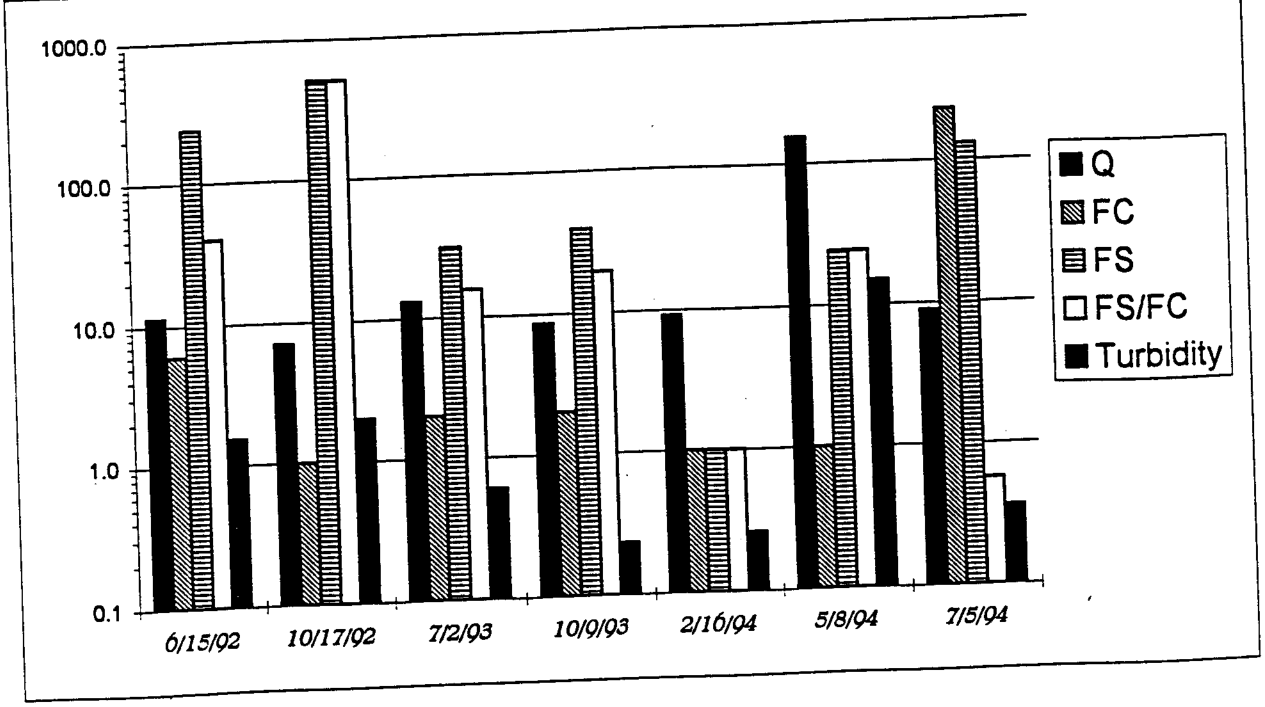
Some tributaries showed high bacteria counts during periods of low turbidity and/or discharge. For instance, Bright Angel creek and Shinumo Creek both exhibited high fecal coliform counts (128 colonies per 100 ml and 230 colonies per 100 ml, respectively). Both of these creeks were in heavy recreational use when the bacteria sample was collected. Turbidity measurements tend to be taken much earlier than the bacteria samples which could have been at the start of such use or directly before. In other instances along these creeks, when turbidity was high, fecal coliform was low and fecal strep. counts were higher. In such instances, discharge was also high as these were samples taken at spring run-off. Neither stream could have been used for water play during spring run-off because of dangerous velocities. Figure 2 shows the fluctuations in bacteria, turbidity and discharge that can occur on Shinumo Creek.

Along some smaller watersheds (with low discharges) this pattern is not as easily seen. Royal Arch Creek tends to show this kind of pattern, but even though it is one of the most visited sites along the river for water play, fecal coliform counts were never high. The highest count (50 colonies per 100 ml) was during normal flows and low turbidity. Fecal strep. was much higher on this creek. Matkatamiba Creek did show one high fecal coliform count during low turbidity, and also showed a low fecal coliform count during higher turbidity which is similiar to the pattern above, except that fecal strep. counts were also low.

Other streams showed high fecal strep. counts during low discharge and turbidity situations. These streams included Crystal Creek, Monument Creek, Clear Creek, Spring Canyon Creek,

Shinumo Creek Bacteria, Turbidity & Discharge





Three Springs Creek, Vaseys Paradise, National Creek, Stone Creek and Hermit Creek. Fecal coliform counts were low on these streams. None are used extensively for water play, except for Stone creek which was never sampled during high use.

Warm Springs Creek exhibited low counts of both fecal coliform and fecal strep. bacteria. Turbidity levels were very low during all sampling periods and water play is very difficult due to thick vegetation. Lava Chuar creek also exhibited low counts of both types of bacteria even during high turbidity instances.

It should be noted that these trends are quite qualitative in nature and have not been put through any statistical analysis. It appears from close review of the data so far, that variability in results can be extremely high depending on discharge levels, turbidity, rain falling in the area and amount of water play. It can safely be said, though, that every tributary sampled was found to have at least fecal strep. present, no matter whether the water was turbid or not. This leads to the postulation that since fecal strep. is most likely from wildlife sources in most instances on these tributaries, giardia could also be present. Although giardia was not sampled in this study, it has been found to be present in most mammals. Therefore, water for drinking should always be filtered on tributaries even though human contamination may not be present.

Trends in Chemical Composition

Some interesting results were found from this portion of the study, because none of the tributaries to the Colorado had ever been sampled with such intensity over different seasons. All results were reported as 'total' concentrations in milligrams/liter (mg/l). Samples were not filtered and acidified in order to obtained dissolved concentrations of specific ions or metals because of the reconnaissance nature of the study. It was decided that total concentrations would be determined as a first baseline and those tributaries with high total values would be considered for dissolved analyses in the future. Total concentrations are used by the state of Arizona for domestic water source and full or partial body contact health standards. Dissolved concentrations are used by the state for wildlife associated standards. Total dissolved solids were analyzed for because they provide a general idea of the dissolved ionic concentrations in waters, though not down to a specific level.

All of the tributaries sampled have the following characteristics: hardness, high alkalinities (i.e. high buffering capacity), consistent pHs around 8.5 and 7.0 mg/l or above for dissolved oxygen, which is the state standard for aquatic life.

Other results can essentially be split between tributaries with low conductivities and low total dissolved solids and tributaries with high conductivities and high dissolved solids.

The tributaries with low conductivities and low total dissolved solids include Vaseys Paradise, Thunder River, Shinumo, Tapeats, Deer, Bright Angel, Saddle, Clear and Stone Creeks. All of these tributaries are primarily fed by springs emitting from the lower carbonate strata (Redwall, Devonian and Muav limestones) and are considered dolomitic springs (composed primarily of calcium, magnesium and carbonates) in the Grand Canyon Water Resource Management Plan (1984). These springs drain from the North Rim and are of the short residence time, high volume category which tend toward even further dilution of sodium, chloride, calcium, magnesium or sulfate during higher water. Likewise, these tend to increase as flows decrease during the summer and fall. Clear and Stone creeks, although having much smaller flows, also exhibit these trends.

This information is not necessarily new, but it does provide a baseline for seasonal changes. In these streams, one does not see significant increases or decreases in ionic concentration or trace metals with changes in discharge or season, which is interesting to note considering the fluctuations in flow these tributaries can experience through the season. For instance, Tapeats Creek ranged from 40 cfs to approximately 150 cfs, Shinumo Creek ranged from 7 cfs to 155 cfs and Vaseys Paradise ranged from less than 1 cfs to 25 cfs during sampling visits. These flows were attributed to both spring run-off and heavy rains (because of the short residence time, heavy rains quickly raised discharge in these streams).

Nutrient levels can increase on the larger of these tributaries with higher flows and/or higher turbidities. For instance, Tapeats creek ranged in total phosphate from 0.05 mg/liter to 0.33 mg/l in its highest flow. Nitrate/nitrite ranged from less than detection level (0.06) to 0.35 mg/l. Though not extremely high, these levels have been known to cause exaggerated plant growth. The state of Arizona does not have a numeric standard for total phosphate but the narrative water quality standards state, "Navigable water shall be free from pollutants in amounts or combinations that cause the growth of algae or aquatic plants that inhibit or prohibit the habitation, growth or propagation of other aquatic life or that impair recreational uses". So far these conditions have not been observed, but they should be monitored in the future.

Tributaries emerging from the lower carbonate strata with high conductivities and total dissolved solids include the Little Colorado River, National, Kanab, Matkatamiba, Crystal, Warm Springs, Havasu, Spring Canyon, Kwagunt, Royal Arch, Hermit, Three Springs and Nankoweap Creeks (listed roughly in order of decreasing total dissolved solids). Results vary enough that each tributary will be briefly summarized.

The Little Colorado River, which drains a watershed of 26,977 square miles, had conductivities ranging from 3800 to over 4800 microseimens/liter and dissolved solids averaging 2500 mg/l during the study. The high dissolved solids can be attributed mostly to high sodium chloride levels. Arsenic levels exceeded the state fish consumption standard (3.1 mg/l) every sampling time, but did not exceed the state full body contact or domestic water source standards. Occasionally levels of zinc, cadmium, copper and phosphate would increase, but never close to a health standard. The variation in these levels did not appear to be related to discharge (which was fairly consistent) or turbidity. It is recommended that the LCR be sampled during flood stages, where some of these constituents may increase significantly.

Sodium chloride was much lower at National Creek (its drainage area is only 187 square miles), the high dissolved solids seem to be attributed to higher calcium and magnesium levels. Sulfate levels were found to be high as well, averaging 1100 mg/l. Although the state does not have a health standard for sulfate, the EPA recommends that levels do not exceed 250 mg/l. These higher sulfate levels like other dissolved solids can bring on a laxative effect. Also at National, the winter sampling period found slightly elevated levels of zinc and nickel.

Kanab Creek drains a 2,000 square mile watershed mostly outside of park boundaries. It was sampled during a flood event where the higher turbidity and discharge was found to have lower dissolved solids than normal but extremely high total suspended solids. This translated to lower sulfate levels than normal, but high arsenic (exceeded fish consumption standard), chromium (exceeded domestic water source standard), lead, zinc, copper, silver, nickel, phosphorus and nitrate/nitrite concentrations. Radionuclide amounts (combined gross alpha and gross beta) were found to be 314 picocuries/liter, well above the state health standard for domestic water sources. During average flows these constituents were still present at lower amounts (no exceedances) and sulfate levels increased to an average of 550 mg/l.

Matkatamiba Creek which has a flow usually less than 1 cfs appears to have high conductivities and dissolved solids from high calcium and extremely high sulfate levels. Zinc was detected as well as selenium. This is one of the few creeks were selenium was in a concentration above detection level. At an average of 1 mg/l it approaches the state chronic standard for wildlife.

Crystal Creek was found to be high in sodium chloride during the study with concentrations of arsenic exceeding the domestic water source and full body contact standard (50 mg/l) in three out of eight samples (three others came within 5 mg/l of exceedance). The fish consumption standard was exceeded by every sample.

Warm Springs Creek, directly downstream of Lava Falls, was found to have warmer temperatures and lower pH than other tributaries as well as high conductivities and dissolved solids. Calcium levels were found to be high as well as arsenic (only fish consumption standard exceeded) and nitrate/nitrite.

Havasu creek had high conductivities and only slightly high dissolved solids. Sodium, chloride, calcium and magnesium appeared to average equivalently over the sample period. The only exceedance found was the fish consumption standard for arsenic for every sample taken, although zinc, lead and copper were also found in small amounts. No fluctuations in concentration were found that appeared to be related to flow or turbidity. Please note that these concentrations could increase during flood events.

The rest of the streams with high conductivities and dissolved solids were also of very small discharge (mostly less than 1 cfs although Nankoweap ranged from less than 1 to 7 cfs). Nankoweap showed increases in sulfate concentrations in relation to discharge increases. Kwagunt also showed high levels of sulfate, but not related to changes in discharge. Hermit creek was low in sulfate, but was high in sodium chloride (Hermit was sampled in two locations and the site below the Tapeats Sandstone, known for its salt deposits was much higher in salt than the site above that layer) and exceeded fish consumption standards for arsenic for every sample analyzed. Gross alpha/gross beta were also found to be close to domestic water source exceedance for Hermit on one sampling occasion. Royal Arch Creek was found to be high in sulfate and to contain small concentration of zinc, selenium and nitrate/nitrite. Spring Canyon creek showed slightly high concentrations of sulfate, plus concentrations of zinc, copper and nitrate/nitrite. Spring exceeded the fish consumption standard for arsenic every time it was sampled. Three Springs creek was high in calcium with small concentrations of lead and nitrate/nitrite. It also exceeded fish consumption standards for arsenic with all samples analyzed.

The remaining four tributaries spring from other rock layers or travel through unique rock layers that have contributed to a distinct chemistry. The Paria River drains a vast watershed that is primarily outside of the park boundary. It originates in rock formations no longer found at Grand Canyon, passing through the Chinle formation composed of decomposed volcanic ash which contributes to its unusual chemistry. At high flows and high turbidity, calcium is high as well as sodium. At high flows the river was found to come close to exceeding domestic water source and full body contact standards for arsenic, exceeding these same standards for chromium, lead, cadium, nickel, beryllium and gross alpha/gross beta. Other high concentrations with no exceedances include zinc, copper, silver, phosphate and nitrate/nitrite.

Lava Chuar Creek originates and/or passes through precambriam and volcanic rock layers as well as flows near an abandoned copper mine. Lava Chuar Creek has been said to be dry at certain times of the year, but this study found it to always have a flow no matter what season for the three years of the study. Sulfate levels are high and increase under high turbidity. Sodium chloride levels are also very high, but usually higher at lower flows. Concentrations of chromium, lead, zinc, copper, nickel and phosphate were found. Arsenic levels exceeded domestic water source and full body contact standards six out of the seven times sampled and gross alpha/gross beta concentrations also exceeded the domestic water source standard.

Monument Creek and Pumpkin Springs both originate from the Tapeats Sandstone layer. Both were found to have extremely high concentrations of sodium chloride as well as calcium and magnesium. Zinc was found at Monument Creek, but not at a level of exceedance. Pumpkin Springs was found to be extremely toxic. Arsenic levels exceeded 1000 mg/l, zinc was found at 198 mg/l. This is the most toxic water sampled and is the only one that recreationists should avoid completely.

As mentioned earlier, aquatic invertebrate collections have not yet been fully analyzed by the state. Identifications made for 1992 did find large numbers of pollution-tolerant species in Hermit Creek, Royal Arch Creek and Spring Canyon Creek. Those creeks with higher dissolved solids including Havasu Creek, Kanab Creek and Paria River were not found to have large numbers of any type of invertebrate. This qualitative information is very inconclusive at this point since more data is yet to be given and multivariate analyses have not been done.

CONCLUSIONS

Many conclusions are yet to be made statistically regarding this data. But conclusions can be made about the general chemistry of these waters and which ones should be avoided as water sources or for recreation. Recommendations can also be made regarding a sampling schedule.

The following general conclusions can be made:

1. The tributaries to the Colorado River with headwaters within park boundaries are probably some of the highest quality waters in the state. Exceedances in trace metals and other constituents are most likely from natural sources within the rock layers that the water comes in contact with.

2. The tributaries to the Colorado River with headwaters outside of park boundaries remain in question as to the origin of their exceedances. Although, rock layers could very well also be the source, especially with the Paria River, other outside activities could be contributing, such as mining in the Kanab Creek drainage. These tributaries definitely need to be monitored continually and perhaps in several locations in cooperation with the states of Arizona and Utah.

3. Bacteria levels, whether of human origin or wildlife origin, can be high and not necessarily at predictable times. High water and turbidity are obviously times of high

SITE NAME	FREQUENCY/YEAR	CYCLE	PARAMETERS
Matkatamiba ck	2 summer/fall 1 summer	odd years every year	chemistry bacteria
National crk.	2 summer/fall 1 summer*	odd years every year	chemistry bacteria
Warm sprgs crk	2 summer/fall	odd years	chemistry
Spring canyon	2 summer/fall*	odd years	chemistry
Three sprgs ck	2 summer/fall	odd years	chemistry
Pumpkin ck	1 fall	every three yr	chemistry
Kwagunt creek	2 summer/fall*	odd years	chemistry
Monument ck	2 summer/fall*	odd years	chemistry

* = event sampling needed for both chemistry and bacteria