Seasonal Use of the Intermittent Virgin River Gorge by Protected Fishes

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INTRODUCTION

The Virgin River extends from its headwaters in southwestern Utah through the northwest corner of Arizona and eastern Nevada to Lake Mead. Similar to other rivers and streams in the desert southwest, the Virgin River exhibits extreme flow fluctuations that cover the range from extremely low clear water base flows during the summer to high base flows during the winter and early spring and raging sediment laden torrents during the rainy periods or during the spring runoff (i.e., snowmelt). In addition, the Virgin River consists of both perennial and intermittent segments. The intermittent segments frequently consist of dry stream bed and/or standing pools during several months of the summer season, but during other times of the year, they experience the same range of flows found in the perennial segments of river. The naturally intermittent segments of the Virgin River include part of the Virgin River Gorge in Arizona and a segment of the lower Virgin River upstream from Lake Mead in Nevada. This study encompasses primarily the Virgin River Gorge from near the Utah-Arizona boarder down stream to a large complex of springs, Littlfield Springs, Arizona (Figure 1).

The native fish fauna of the Virgin River is relatively depauperate, which is partly attributed to the harsh environmental conditions (Cross 1975,1985). The native fishes consist of two endangered species, woundfin (*Plagopterus argentissimus*) and Virgin River chub (*Gila seminuda*), and four other species, desert sucker (*Catostomus clarki*), flannelmouth sucker (*Catostomus latipinnis*), speckled dace (*Rhinichthys osculus*) and Virgin spinedace (*Lepidomeda mollispinis*). The Virgin spinedace is currently protected by a multi-agency conservation agreement with the express goal of removing threats to the species. Up to 14 nonnative species have been found in the Virgin River system; however, most are rare in the main stem Virgin River. The most abundant nonnative is the red shiner (*Cyprinella lutrensis*). Red shiner have been implicated as a primary cause of the rapid decline in native species, particularly woundfin, roundtail chub and spinedace, upstream and downstream of the Virgin River Gorge (USFWS 1996). Other species that are frequently collected in the Virgin River include black bullheads (*Ictalurus melas*), largemouth bass (*Micropterus salmoides*), mosquitofish (*Gambusia affinis*), channel catfish (*Ictalurus punctatus*), and carp (*Cyprinus carpio*).

Water development on the main stem Virgin River for agriculture and domestic use has resulted in several water diversions in Utah, Arizona, and Nevada, and an off-stream reservoir in Utah (Quail Creek Reservoir finished in 1985). The long term irrigation diversions and storage of winter and spring flows in Quail Creek Reservoir with subsequent summer deliveries of this water downstream of the reservoir to the Washington Fields Diversion have altered flow patterns in the Virgin River. In addition, water diversions and storage projects on tributary streams (e.g., Santa Clara River) have contributed to changes in the flow regime within the main stem. These alterations have likely reduced the frequency and magnitude of natural intermittent flows within the Virgin River Gorge although data does not exist to quantify the changes. Diversion structures along the Virgin River have also created barriers that affect upstream movement of fish. The closest diversion structures in the vicinity of the Virgin River Gorge are 14 miles upstream (Johnson=s Diversion) and 14 miles downstream (Bunkerville Diversion), and likely

have limited impact on fisheries in the Virgin River Gorge.

Fish movement at the top of the Virgin River Gorge in Utah, however, has been impacted by the approximately 4 foot high Red Shiner Barrier (Figure 1, Plate 1) installed in 1988. The Red Shiner Barrier was constructed to stop the invasion of red shiner into the upper Virgin River. Although red shiner currently exist above the barrier, ongoing eradication of red shiner by chemical treatment remains a priority for recovery actions. In 1988, upstream chemical treatment was attempted. The treatment was unsuccessful and because of poorly timed detoxification at the Red Shiner Barrier, the treatment resulted in the loss of an undetermined number of native fish within the Virgin River Gorge and downstream of the Gorge as far a Mesquite, Nevada (USFWS 1996). In 1989 another upstream chemical eradication was attempted (the treatment was detoxified at the Red Shiner Barrier), but was unsuccessful in removing red shiner from the reaches upstream of the barrier. At the present time, another upstream chemical treatment is in the preparation stage upstream of the Red Shiner Barrier.

The purpose of this study was to better understand the seasonal use of the Virgin River within the Virgin River Gorge by native fish species during the summer period when declining flows result in intermittently dry sections of river. Specifically the goals were to quantify changes in the use and availability of macrohabitat within the Virgin River Gorge as a result of declining flows and to quantify movement of fishes in response to the drying conditions. A better understanding of the use of the Virgin River Gorge by native fishes has potential ramifications on how both water and fisheries are managed (e.g., flows and fish barriers) in the Virgin River. It also has the potential of providing a better scientific understanding of fish behavior in response to intermittent flows and the potential consequences to fish of intermittent flows.

The original objectives and sampling design of this study required alteration during implementation due to a series of uncontrollable events. Following preliminary notification of study approval for the 1995 field season, unexpected delays in contract approval precluded starting field work until late July, 1995. This made the collection of critical early summer field data impossible. Shortly after field data collections were initiated, flow conditions within the study reach became highly dynamic and an unusually rapid, but short duration drying of the stream channel occurred. This required severe modification of sampling methods and goals, especially in light of the size and access limitations within the study area. Due to these constraints and limited data to meet research objectives, USU provided additional research monies from the INSE research program to support the collection and analysis of additional data during the summer of 1996. Some discussion of these issues and constraints in light of the original study objectives and sampling design is presented in this paper for completeness, however, the main objective of the paper is to present the data obtained from this study (altered as it may be from the original study design) in conjunction with historical sample collections to meet the original study goals of understanding fish habitat use in the Virgin River Gorge.

METHODS

Study Site

The primary study segment of the Virgin River where new data were collected and historic data were analyzed was the 20 mile segment of Virgin River within the Virgin River Gorge (Gorge). The upstream end of the gorge begins approximately 3 miles upstream of the Utah-Arizona boarder near the Red Shiner Barrier Dam at River Mile (RM) 59.67 and the downstream end is 5 miles upstream of the confluence of Beaver Dam Wash with the Virgin River in Arizona (RM 39.69 (Figure 1). We also included in the study site historical data collections near the top and bottom of the Gorge. At the top of the Gorge historic data collected between the Red Shiner Barrier Dam and the Virgin River Fishes Recovery Team (VRFRT) Atkinville biannual sampling station near Bloomington, Utah, (RM 66.62) were included in the study. At the bottom of the Gorge historic data from the VRFRT Near Beaver Dam Wash sampling station (RM 34.95) at the confluence of Beaver Dam Wash were included along with other historical collections between RM 34.95 and 39.19 (Figure 1).

Habitat within the Gorge varies considerably from the low gradient, wide sandy river channel found throughout much of the main stem Virgin River in Utah, Arizona, and Nevada. The gradient in the gorge is steeper (0.55%) compared to other sections of the Virgin River (0.3%), and within the gorge the narrow, rocky canyon confines the river and allows only limited development of flood plain features and riparian vegetation, which is dominated by introduced Tamarisk. Mesoscale habitat within the gorge consists of rocky riffles interspersed with deep pools created by turbulent scour at the base of rock ledges and only a limited number of long sandy runs can be found. Both the upper and lower ends of the study site outside of the Gorge are more typical of main stem Virgin River habitat. Upstream of the Gorge from the Red Shiner Barrier to the Atkinville VRFRT sampling station the river consists mostly of wider, shallow sandy runs and little deep water fish habitat (Plate 1). From the downstream end of the Gorge to the confluence of Beaver Dam Wash the river is wider than in the gorge and consists of a diverse mixture of riffles, numerous boulder strewn sandy runs, and a few relatively deep pools.

At the present, flows upstream of the top of the Gorge near the Red Shiner Barrier, are typically perennial, but are extremely low (a few cfs) during most summers. During summer low flows, the majority of the discharge is made up of return flows from the Washington Fields and Santa Clara agricultural areas and releases from the municipal wastewater treatment plant (ca. 5 cfs) at Bloomington. During these low flows the entire river frequently seeps into the streambed and the river can become dewatered at times from the upper Gorge downstream to the beginning of the Littlefield Springs at River Mile 42. Inflows from Littlefield Springs consist of numerous (70) small springs (0.1 to 3.0 cfs) that emerge along a seven mile section of river from inside the lower end of the Gorge down river to Beaver Dam Wash (Figure 1). The combined total flow of the springs is 60 cfs (Trudeau 1979; cited in Sandberg and Sultz 1985).

Sampling

Original Sampling Design--As mentioned previously, due to unexpected delays in contract approval (late July), sampling difficulties, and an unexpectedly quick drying within the Gorge during the summer of 1995, our initial one year sampling design was drastically disrupted. In addition, after initiation of field work in 1995, a better understanding of dynamic flow conditions, fish habitat issues in the Gorge, and the logistics associated with sampling these conditions resulted in the realization that some of the original study design was impractical or of limited value.

The original study design consisted of monitoring changes in macrohabitat availability throughout the Gorge (reach wide watered and dewatered habitat) and use of this habitat by fishes prior to, during, and after stream drying. The design also consisted of monitoring mesoscale habitat (e.g., run, pool, riffle) quality versus habitat use by fishes in four test sections using field mapping and cross-section monitoring techniques. We also planned to tag a large number of fish prior to stream drying within the Gorge to record movement of recaptured fish after drying occurred.

Reasons For Modifying The Original Sampling Design--While considerable effort was expended in installing head pins and collecting cross-section data for the mesoscale habitat monitoring in the beginning of the study (actually prior to contract approval), the cross-section data collection was abandoned. In total, initial data for 35 cross-sections at four test segments of river (below the Red Shiner Barrier, at two locations in the middle of the Gorge, and one site at the bottom of the Gorge) were collected. The late starting date combined with rapid late summer flow fluctuations (declining flows and within day fluctuations) and the logistics associated with measuring cross-section data and sampling fish under the declining/fluctuating flow resulted in this component of the original study design being unworkable.

Due to rapid declining flows (including within day drying and wetting of the channel), manpower was shifted to sampling fish throughout the length of the Gorge to determine densities in an attempt to understand the large scale effects of habitat de-watering on fishes during and after the drying. In particular sampling and marking a large number of fish from the area near the middle of the Gorge was attempted to determine movement patterns of fish based on subsequent recapture following de-watering of this section of river. Following de-watering and subsequent re-watering of the Gorge in 1995, field sampling was stopped to reserve a small amount of financial resources for single re-sampling of the Gorge during the following summer de-watering event (1996). As noted previously, additional funds from the INSE research program were used to supplement these efforts.

Modified Sampling Design--Based on the experiences gained during the initial sampling, the modified sampling design in effect consisted of sampling at 13 approximately equally spaced sampling locations throughout the Gorge prior to, during, and after the 1995 de-watering to determine densities and spatial location of fishes. Sampling sites were chosen to provide a broad coverage of key locations in the Virgin River Gorge and to take advantage of sites where previous data had been collected. Initial sampling typically consisted of mapping the mesoscale

habitat units within each sampling site and sampling habitat units approximately in proportion to their availability. Rocky riffle habitats were not sampled most of the time, however, because the bulk of the sampling was undertaken by seining which is not effective in these habitats. Total sampling effort typically consisted of 5 to 10+ fish samples sites per sampling location. Following the initial sampling of extensive habitats, each station was sub-sampled. During declining flows, pools were the most stable habitat type and contained the most fish, so the sub-sampling concentrated on re-sampling pool and other deep water habitats in the same location and manner as they were sampled initially. During the 1996 de-watering event, 6 of the original 1995 sampling stations were re-sampled. In addition, one new habitat location was identified as providing critical deep water habitat conditions and sampled for the first time.

Sampling was accomplished using nylon seines and snorkeling. Seines were made of 3.2 mm mesh and were 4.5 m long. Seine sampling was accomplished using a combination of single pass seine hauls and 3 multiple pass seine hauls. The length of the samples was determined by the length of the habitat units. Typically in open ended pools a blocking net was used to deter downstream escapement of fish during sampling. All captured fish were identified, enumerated, measured, checked for tags, and released back into the stream. Snorkeling was used to provide accurate counts of adult fish in deep water and was only used in instances where water clarity provided excellent visibility. Young-of-the-year (YOY) fish were not enumerated during snorkeling.

During initial sampling in 1995 adult fish captured in the middle of the Gorge prior to drying were tagged with a color latex injection in one fin. The color and fin location of tags was used to denote capture locations. Subsequent recaptures were noted and the amount of movement from the initial tagging location was noted.

Historic accounts and records of flows in the Gorge were obtained from the literature and from the USGS Virgin River gage Near St. George (#9413500) and the Littlefield gage in Arizona (#9415000). Discharges at the top of the Gorge during the study were obtained from the Near St. George gage. Discharges at other places in the Gorge were determined using standard gaging techniques using a Swoffer or Marsh McBirney digital velocity meter. Photographs were used to document fish kills and physical habitat. Sampling locations and de-watered reaches were marked on 7.5 minute USGS quads. Habitat mapping at sampling stations was sketched on data sheets.

Data from historical Virgin River Fishes Recovery Team (VRFRT) sampling sites at Beaver Dam Wash, Cedar Pockets, and Atkinville Wash were used to show historical fish abundance trends in the Virgin River Gorge. Additional miscellaneous data collected within the Gorge since 1992 by the BLM and others were used where applicable to provide baseline information. Data collected during the 1995 and 1996 summer drying events are used to show fish distribution during the events. For all of the data analysis, native fish were separated into young-of-the-year (YOY) and adult size classes based on lengths from Addley and Hardy (1995). The size separation between adult and YOY was 55 mm (woundfin), 50 mm (speckled dace), 90 mm (flannelmouth sucker), 90 mm (desert sucker), 68 mm (spinedace), 90 mm (Virgin River chub),

and 36 mm (red shiner).

RESULTS

Sampling Locations

A combined total of 13 locations where sampled during the 1995 and 1996 field work (Figure 1). During 1995 12 sampling sites were located at River Mile 39.69 (Below Mouth of Gorge), 40.27 (Above the Station Below Mouth of Gorge), 41.33 (Above Pylon Bridge & Below Second Bridge), 42.04 (Between Big Ten and Springs), 42.81 (Big Ten), 44.40 (Below Dave=s Rock), 49.10 (Above Campground), 49.78 (Gorge Above Corral), 51.41 (Mile Marker 21 Gorge), 52.89 (Small Bend), 5.08 (North of Top Bridge), and 58.67 (Red Shiner Barrier). Six of these sites were re-sampled in 1996, River Mile 39.69, 41.33, 49.10, 51.41, 55.36, and 58.67. One additional site was added at River Mile 40.76 (Cable Across River). Each sampling site was 10-20+ channel widths long.

Habitat Mapping

Prior to the study, during June 1994, the entire Gorge from the Red Shiner Barrier down river to the mouth of the Gorge was mapped to determine the linear measurement for each habitat type (Hardy et al. 1994). Because of the large distance involved, small habitat units (i.e., pocket side pools) were not delineated. Only habitat units larger than about 1-2 channel width long were classified. The linear location of runs, pools, and riffles from the Barrier downstream are shown in Figure 2. In the upper Gorge, above the Cedar Pockets Campground, runs are the dominate habitat type and pools are relatively rare. In the lower Gorge, from near Cedar Pockets Campground downstream, a more diverse mix of runs and riffles occurs and pools become much more abundant.

Habitat mapping at each of our sampling sites in 1995 and 1996 shows this trend in more detail. Figure 3 shows the percentage of pools, runs, and riffles within each of our main sampling sites. Clearly most of the habitat in the upper two sampling sites River Mile 58.67 (Red Shiner Barrier) and River Mile 55.08 (North of Top Bridge), is composed of runs. Beginning at River Mile 49.1 (Above Campground), pools become more abundant and a relative diverse mix of pools, runs, and riffles occurs. Copies of sampling station site maps with habitat delineations for each of the sampling sites are shown in Appendix A (note that glide habitats on the maps were considered to be shallow runs in the final analysis).

Qualitative/Quantitative Observations of Flow

Historic Conditions--Historical information on the Virgin River prior to agricultural development in the late 1800's either doesn=t exist or was unavailable to us. Sketchy data from the early 1900's, after significant agricultural development began, indicates that the Virgin River periodically went dry in the Virgin River Gorge. Adams (1903) documented that during May 1902 (a dry year) the river was completely dry A6 miles below Atkinville.@ This is near the current Red Shiner Barrier. Flow records are available from the Virgin River Near St. George from 1950 -1956 and 1991- present. This gage is located at the present day Red Shiner Barrier. Flow records from the 1950s show that the river went dry every year at the gage (Red Shiner Barrier). This typically occurred between late May and September (Figure 4). U.S. Geological Survey personnel measured seepage losses near the gage of 36 to 106 cfs in 1952 and 1956 (Sandberg and Sultz 1985), and the U.S. Bureau of Reclamation estimated average annual loss in this location of 50 cfs (USBR cited in Sandberg and Sultz 1985).

It is obvious that historically the Gorge was frequently dry, likely on an annual basis in all but above normal precipitation years. The extent of dry conditions through the length of the Gorge, however, is unknown to us. We suspect that when the river was dry at the gage (near the present day Red Shiner Barrier), the entire 18 miles of the Gorge down to the beginning of Littlefield Springs was also dry.

Current ConditionsC The recent discharge records from the St. George gage reestablishment in 1991 to the present (post Quail Creek Reservoir closure in 1985) show that there is always flow at the gage, but low flows of 15-30 cfs are common (Figure 5). These limited data indicate that more flow exists now at the gage than historically and that intermittent conditions have likely changed in the Gorge. This likely is the result of summer flow releases for irrigation from Quail Creek Reservoir and the wastewater treatment plant releases near Bloomington, Utah.

Although it appears, that at the present, more summer flow occurs in the Gorge than occurred historically, sections of the Gorge still typically become intermittent on an annual basis during the summer. Data collected by the BLM indicate that when flows are in the range of 35-40 cfs at the St. George gage, sections of the Virgin River Gorge go dry (Stephanie Ellingham, Pers. Comm.). This was supported during our field work in 1995 and 1996. During August 8-12, 1995, flows went dry in the middle Gorge following several days of flow in the mid 40 and high 30 cfs range at the St. George gage. During June 1-6, 1996, flows went dry in the Gorge immediately following flows in the low 40 and high 20 cfs range. The six mile section of stream from the Cedar Pocket Campground downstream to the beginning of the Littlefield Spring inflows at River Mile 42 was the section of river that typically went dry first and stayed dry the longest. In recent years, dry conditions or standing water typically has been observed along 12 miles of the river from near the first bridge in the Gorge (river mile 54.5) downstream to the spring inflows (Stephanie Ellingham, Pers. Comm.).

During the summer of 1995 and 1996 when dry conditions occurred in the Gorge they were temporally and spatially very dynamic. Typically, when flows first started to dry up, large sections of river would quickly go from having substantial flows to being dry during a period of several hours in the early afternoon (about 2 pm). This would occur between the Cedar Pocket

Campground and River Mile 42 (7 miles). Later in the evening (e.g., 7 pm) or at night as air temperature declined, flow would start to reappear in an upstream to downstream direction. This frequently caused temporally isolated pools in the Gorge that were reconnected at night and during the early morning. During early August 1995, this happened for several days allowing most fish to work their way out of the drying section of the Gorge with very little mortality. Later in August, flows in the upper Virgin River increased (due to releases of irrigation water from Kolob Reservoir in the headwaters of the Virgin River) and continuous flow reestablished throughout the Gorge.

During 1996, drying in the Gorge happened earlier in the year (June 1-6), occurred more quickly and persisted longer. The section of Gorge from near Cedar Pockets Campground downstream to Littlefield Springs remained continuously dry immediately following the first few days of drying. Some re-watering on the upper end near the campground would occur in the evening, but the re-watering did not extend very far downstream. Several times we followed water moving slowly down the channel during the late evening, rechecked the progress of the flows early the next morning and found that flows had not extended far downstream. The quicker, more permanent drying during 1996 stranded many fish in the de-watered section.

Some attempt was made to understand quantitatively how flows were behaving throughout the Gorge, but due to the dynamic flow conditions, long study reach and limited access in many places, this was extremely difficult. An example of 5 flow measurements taken throughout the day on the 12th of August, after flows were reestablished throughout the Gorge (following a dry period in the middle of the Gorge the previous day), shows some of the spatial variation in flow (Figure 6). About a 60 cfs loss of flow can be observed between the Red Shiner Barrier and the Below Dave=s Rock (14 miles) station. This flow loss may be slightly exaggerated because the flow measurement at the Red Shiner Barrier was taken about 2 hours later in the evening than the measurement at Below Dave=s Rock. This was about the time in the evening flows typically started to increase as a response to cooling temperatures.

Fish Mortality

During the summer of 1994, Mike Herder (Pers. Comm.) observed dead and stranded fish in the Virgin River Gorge when the middle section of the Gorge dried up. During drying of the Gorge in August 1995 only a few scattered individual fish mortalities were observed as part of this study. During afternoon drying, fish were frequently trapped in isolated pools; however, in the late evening, night and early morning, flow reconnected the pools allowing fish to move out of the drying area. During early June 1996, however, rapid, permanent drying in the Gorge trapped large numbers of adult and young-of-the-year (YOY) fish. Completely dry sections of streambed and small isolated pools, particularly in the lower half of the dry section from river mile 45 downstream (Figure 1), contained large numbers of dead and dying native and nonnative fish (adult, juvenile, and YOY) (Plate 1). No dead woundfin or Virgin River chubs were found. We attribute this to the rarity of these species in this section of the lower Virgin River. We observed little selectivity in terms of dead species, except for perhaps that we saw many dead adult desert suckers and few dead adult flannelmouth suckers in comparison to the relative

abundance of these two species. We also observed dead fish in the upper portion of the Gorge in the vicinity of river mile 55. This section of river had continuous running water and live fish in deep water habitats, but there were small piles of dead fish that had washed into low velocity sections of the river (Plate 1 and 2). We attributed these dead fish to heat/oxygen stress, however, some drying may have occurred that we did not observe.

Historic Population Data

Data from the standardized Virgin River Fishes Recovery Team sampling for the Near Beaver Dam Wash, Cedar Pockets, and Atkinville Wash sampling sites are presented in Tables 1-3. Table 1 shows the rapid decline in woundfin and spinedace near Beaver Dam Wash beginning in about 1984 at the same time when red shiner numbers increase rapidly. What appears to be a similar trend of decreasing numbers of Virgin River chub is also evident in the data, except that the decline is lagged a few years. Red shiner, although present in the lower river since the 1960's, were captured upstream in Utah for the first time in 1984 (Hickman et al. 1987). Deacon (1988) hypothesized that perhaps red shiner were first able to make it upstream through the intermittent Virgin River Gorge during the exceptionally high summer flows of 1983, and that the establishment of red shiner upstream of the Gorge played a role in allowing red shiner to become the dominate fish below the Gorge at Beaver Dam Wash in subsequent years. An alternative hypothesis is that less frequent high flow events during the dry years following 1983 is responsible for the shift in dominance of red shiner (e.g., Leo Lentsch, Pers. Comm.).

The much shorter data set at Cedar Pockets (beginning in 1992) is not useful for observing trends, but indicates the current relative abundance of native fish and red shiner in the middle of the Gorge (Table 2). Cedar Pockets is at the top end of the section of river that becomes intermittent on a regular basis during the summer and it shows low numbers of all native species, but indicates that native fish are consistently present in this reach of river when flows are continuous. Red shiner are by far the most abundant fish.

The data from Atkinville Wash show the same trend of increasing numbers of red shiner and decreasing Virgin River chub and woundfin numbers as occurs at the Near Beaver Dam Wash site, although the trend is not quite as dramatic (Table 3). Currently low numbers of Virgin River chub and flannelmouth sucker and sporadically low numbers of woundfin occur at the site. The one high density sample of woundfin in 1996 likely resulted from salvaged woundfin being relocated to this reach after chemical treatment operations upstream in the area immediately below the Washington Field Diversion. Desert sucker numbers in this reach appear to have remained relatively constant. Large increases in red shiner numbers beginning in 1992 occurred two years after chemical treatment of this reach to remove red shiners.

1992 Intensive Spatial Sampling

In the early summer of 1992 intensive spatial sampling of much of the main stem Virgin River was conducted, including the Gorge study site. A compilation of this data has never been published to our knowledge. Sampling sites were located approximately every mile through the Gorge study section. At each site, three samples in representative habitat types were taken. Every other sample site was either a qualitative sampling site or a quantitative sampling site. Qualitative sampling consisted of only a single seine haul at each seining location and quantitative sampling consisted of three seine hauls within a specific habitat site. The average fish density for the first seining pass at each of these sampling sites is presented in Table 4. No spinedace were found within the study area which is not surprising because spinedace are typically a headwater and tributary species and are abundant only in the upper mainstem Virgin River above Hurricane, Utah, and in tributary streams (e.g., Addley and Hardy 1993). Relatively low and sporadic densities of the other native species were found throughout the length of the study reach. Nonnative red shiner were by far the most abundant species throughout the Gorge.

Qualitative / Quantitative Observations of Fish

General Qualitative Observations of Fish Behavior, Summers 1994, 1995, and 1996--During the summer of 1994, Mike Herder with the BLM sampled through the Gorge study site using seines, dip nets and snorkeling. During low flows in early June, he observed large fish, likely suckers or chubs, trying to jump upstream over the Red Shiner Barrier. No fish were successful in negotiating the Red Shiner Barrier during the observation period. At slightly higher flows, velocities at the base of the barrier were too high and there was no place for fish to stage in an attempt to clear the Red Shiner Barrier (Plate 1). Herder also observed while snorkeling that red shiner were very aggressive and frequently nipped at his bare skin. Shiners were found in nearly all habitat types. Native fish were found only in what appeared to him to be higher quality habitat, e.g., deeper water (Mike Herder, Pers. Comm.).

In reaction to the initial stages of drying in the Virgin River Gorge in August 1995, particularly on the afternoon of August 9th at River Mile 50, we observed large schools fish moving downstream in what is best described as migration waves. From visual inspection, the fish appeared to be mostly desert sucker. They moved downstream through shallow water in schools of 10 to 50 fish, held temporally in deeper water habitats and then moved downstream again. At the peak of this movement a new school of fish would appear every few minutes. This behavior was observed only during the first couple of days of the drying period.

Following drying during 1995 and 1996, we observed large schools of adult fish concentrated in pools at the bottom of the Gorge (at Littlefield springs) downstream of the dry section. We also observed large concentrations of fish in the few pool(s) immediately below the Red Shiner Barrier at the top of the Gorge.

At the bottom of the Gorge near the beginning of Littlefield Springs, where flows were still relatively low (e.g., 20 cfs), schools of fish were concentrated in the deepest water available,

which were very shallow pools. Plate 3 shows a school of predominately flannelmouth sucker in a shallow pool. These fish stayed together and were reluctant to move from the relative cover of the shallow pool. All of these fish were easily captured using seines (Plate 3). Farther downstream where flows were greater, each deep pool contained similar large schools of adult flannelmouth sucker, while the faster flowing water in runs and riffles contained large numbers of desert sucker (see snorkeling discussion below). At the top of the Gorge immediately below the Red Shiner Barrier the pool(s) contained large numbers of adult Virgin River chub (Plate 1). One seine pass in the pool adjacent to the Red Shiner Barrier (Plate 1) on August 12, 1995, yielded 86 adult chub. Sampling in this same pool and two others just downstream on June 6, 1996, yielded an average of 23 adult chub per pool.

During low flow conditions the availability and location of pool habitat and deep run habitat was the main determinate of the number and location of fish in a reach. At low flows, shallow water habitats were nearly devoid of fish. All species of fish were confined to pools and deep runs. Only rarely were fish observed in shallow water habitat and these were typically very small fry.

From our observations, the low flow conditions and the subsequent crowding of fish into low flow pools with limited space appeared not only to provide the potential for habitat availability to limit fish numbers, but for significantly enhanced predation and the potential for enhanced spread of disease. While snorkeling during low flow conditions (discussed below), several adult chubs were observed making rapid predatory movements toward YOY fish. Although we observed no successful attacks it appeared that chubs were preying on YOY fish and it appeared there was relatively little refugia for the YOY fish outside of the pools because of the low flow conditions. In the confined conditions of laboratory aquaria during some previous studies on osmoregulation (Addley and Hardy 1995), we lost a number of YOY woundfin due to predation by larger chubs. In addition, while seining during low flow conditions at River Mile 51.4, predation by a relatively small juvenile largemouth bass was observed. A captured 110 mm largemouth bass had a partially digested 55 mm desert sucker in it stomach (the tail of the sucker was sticking out of the mouth of the bass).

SnorkelingBImmediately following drying in 1996, clear water conditions in the lower portion of the Gorge provided an excellent opportunity for snorkeling. We snorkeled 324 meters of stream in the upper Littlefield Springs area at River Mile 40.32 (Cable Across River site) to accurately enumerate fish species and density (Figure 1). This section of stream appeared to provide some of the best refugia habitat for fish fleeing the de-watered conditions in the middle of the Gorge. Habitat in this area consisted of numerous excellent deep water pool habitats mixed with runs and riffles (Plate 3). Abundant YOY flannelmouth and desert sucker were present. There were also a lesser number of adult red shiner (YOY red shiner were not present yet). YOY fish and red shiner were not enumerated while snorkeling, only the adults of larger fish species were counted. We counted 1639 adult fish--26 Virgin River chub, 514 flannelmouth sucker, 1080 desert sucker, 2 woundfin, 6 juvenile channel catfish, and 3 black bullheads. There was a total of 8,149 adult fish/mile or an average 5.7 adult fish/10 m^2. Densities of adult fish were very high. Typically 200 or more adult fish were crowded into each deep pool (typically

flannelmouth sucker, Virgin River chub, and desert sucker) or run (typically desert sucker). In individual habitat units (e.g., pool, runs) densities often exceeded 20 fish/10 m^2. Clearly this section of river was experiencing severe overcrowding while providing refugia to fish that had moved downstream out of the de-watered conditions in the middle Gorge.

We also snorkeled some short sections of deep water habitat at the Below Mouth of Gorge site (RM 39.69) following de-watering in 1996. Several ›pools= existed at this site, but only one large deep water pool existed in this section of river in comparison to the numerous excellent pool habitats at the Cable Across River site. This pool contained 99 adult flannelmouth suckers, 26 desert suckers, and 1 chub. The density was 8.3 fish/10 m^2. This is a relatively high density, but only about half of the densities found upstream at the Cable Across River site. In addition, because no other comparable deep water habitats existing in the area, the total number of fish in the reach was lower than that at the Cable Across River site.

Seining Fish DensitiesC During and following the drying events in 1995 the 12 sampling locations were sampled to determine spatial distributions and temporal changes in fish density (Table 5). Because of difficulties mentioned at the beginning of this paper the amount of sampling time was very compressed and when flows started to decline quickly in early August a compromise sampling scheme had to be implemented that balanced the time available for sampling with the need to know the broad spatial distribution of fish throughout the 20 mile Gorge and with the need to know the specific effects of drying and flow changes at particular locations. Generally we sacrificed repeated, quantitative samples over time at a few selected locations for broader more qualitative spatial sampling along the length of the Gorge. With limited resources we repeated some of the broader sampling initiated during 1995 at the time of drying in 1996.

Data from the 1995 and 1996 sampling are shown in Table 5 along with additional data collected in the Gorge from 1992 through 1994 for reference. Maps of each sampling site and fish sampling locations within each site are shown in Appendix A. Prior to drying, native species were found throughout the Gorge (also see Tables 2 and 4). Although native fish densities are relatively low, particularly when compared to red shiner numbers, it is obvious that considerable use of the entire 20 mile segment of the Gorge occurs when it has flow throughout its length.

Red shiner are by far the most abundant species in the Gorge, followed by desert sucker, flannelmouth sucker, Virgin River chub, and speckled dace. Woundfin and spinedace were very rare. Excluding samples immediately below the Red Shiner Barrier, only 20 woundfin and 4 spinedace were captured in the Gorge in over 250 seine passes. Exotic fish were also found in low numbers. We found channel catfish, black bullhead, and large mouth bass (19), carp (1), and mosquitofish (1).

Repeat sampling of individual pools at various sampling sites in the middle Gorge prior to, during, and following drying showed that native fish did not leave habitat in the intermittent section of the Gorge until being forced out by large scale de-watering. Figure 7 shows an example of flannelmouth sucker and Virgin River Chub densities from two pools in the section

of river that eventually went dry in 1995 (one pool at River Mile 49.1 and one pool at River Mile 44.4). Densities were relatively stable until de-watering began to occur on about August 7th. After de-watering occurred these native fish left the pools even though standing water remained and at times (typically at night) flow connection between pools was reestablished.

Following drying, fish were found both below the drying section from Littlefield Springs downstream and in the upper Gorge above the dry section. In the upper Gorge native adult fish were most abundant immediately below the Red Shiner Barrier (e.g., see sampling dates August 11-14, 1995, and June 4-7, 1995). Figure 8 shows an example plot of the fish densities immediately following drying on August 11 and 12, 1995. The greatest densities of Virgin River chub in the watered section of river were at the upstream end of the Gorge at the Red Shiner Barrier. The greatest densities of desert sucker and flannelmouth sucker were found at the lower end at Littlefield Springs.

Tagging Results--Prior to drying in 1995 a total of approximately 100 adult fish, flannelmouth, desert sucker and Virgin River chub, were tagged from locations in the middle of the Gorge. Most of these fish were originally captured and tagged at the River Mile 49.10 and 44.40 sampling sites. These sites are located in the section of the Gorge that goes dry first, particularly the River Mile 49.10 site. After drying had occurred in the Gorge, two tagged fish were recaptured during sampling in the sections of river that remained watered. The low number of recaptures occurred because of the large study reach and small number of tagged fish. A 420 mm flannelmouth sucker tagged at river mile 44.4 prior to this area drying up, was found three miles downstream in the Littlefield Springs section at river mile 41.3 on August 11, 1995. A 240 mm Virgin River chub tagged at river mile 49.10 prior to drying was found 1.5 miles upstream at river mile 51.4 on August 12, 1995.

DISCUSSION

It is clear that native fish use habitat throughout the Gorge when it-s available (seasonally). This occurs even though on an annual basis, a minimum of about seven miles of the Virgin River Gorge becomes intermittent and an even larger segment frequently becomes intermittent or experiences very low flows during the summer. The majority of the pool habitat exists in the lower portion of the Gorge from about River Mile 49 downstream. This section of river has a good mix of pools, runs, and riffles. The upper section of the Gorge however is dominated by sandy run habitat and has fewer pools and riffles. Under normal flow conditions pool habitat is likely most important for Virgin River chub and flannelmouth sucker, sandy run habitat is perhaps more suitable for woundfin, and rocky run and riffle habitat is mostly inhabited by desert sucker. Particularly during low flows, however, the amount and location of deep water

habitat appears to control the number and location of all native adult fish.

Prior to dry conditions, native fish density was relatively low and scattered throughout the Gorge. Nonnative red shiner were by far the most abundant species, followed by desert sucker, flannelmouth sucker, Virgin River chub, and speckled dace. Woundfin and spinedace were very rare. Other nonnative fish such as black bullhead, channel catfish, mosquitofish and carp were found in low numbers.

Following low flows and drying in the Gorge, adult fish of all native species were found primarily in deepwater habitats (mostly pools and deep runs) and fish densities downstream and upstream of the dry segment were high, particularly downstream at the mouth of the Gorge in the Littlefield springs section. High densities of fish in pools immediately below the dry section highlight the potential predation/disease problems associated with low flow crowding (e.g., Heckmann 1986) and indicate the extreme importance of habitat in this section of river for sustaining or providing refugia for the native fish population that seasonally utilizes the middle Gorge. Although Virgin River chub and particularly woundfin were relatively rare throughout the entire study area, our results suggests that this reach of river is important potential habitat for future conservation of these species. Any large scale flow depletions in the Littlefield Springs reach of river (downstream of River Mile 44) during the summer season could cause serious consequences for these native fish.

Relatively high densities of Virgin River chub immediately below the Red Shiner Barrier and observations of Atrapped@ fish trying to jump the barrier, indicate that although the barrier may eventually be an important feature in eradicating red shiner, at the present it is likely a detriment to the native fish population by not allowing fish to move upstream into better flow conditions during the summer. In the absence of the barrier, the Gorge could provide an expanded amount of fall, spring, and winter habitat that could be exploited by native fish in the upper river. This would require, however, the behavioral trait by these fish of moving upstream during drying conditions in the summer. Our tagging data and sampling data were insufficient to determine how much upstream movement of fish occurred. It does appear from our limited data that many Virgin River chub were moving upstream. The one tagged chub that was recaptured had moved upstream and the concentration of chubs in the pools immediately below the Red Shiner Barrier indicates this same trend.

Conversely, it appeared that a majority of movement of flannelmouth sucker and desert sucker was downstream based on the large concentrations of these species in the Littlefield Springs area following de-watering and based on our visual observations of fish moving downstream. There may also have been some limited upstream movement, however.

Due to the large distances involved and difficulties associated with marking large numbers of fish for subsequent recapture, the best way to more definitively determine long distance movements of large native fish (Virgin River chub, flannelmouth sucker, and desert sucker) associated with drying conditions in the Gorge is to equip fish with radio tags. Information concerning movement patterns of large adult native fish in the Gorge and throughout the Virgin

River will continue to be uncertain, as evidenced by this study, without a concerted effort to implement a radio tagging and tracking program. For the smaller species, woundfin, spinedace, and speckled dace, smaller scale marking/tagging and recapture studies appear to be the only way of monitoring movements because of the inability to implant radio tags in these small fish. This is very problematic due to the limited number of fish available for marking and the difficulties associated with recapturing fish.

The disappearance of woundfin in the study reach, beginning approximately in 1984 at Beaver Dam Wash and the disappearance of Virgin spinedace at the Beaver Dam Wash confluence coincident with rapid increases in red shiner numbers implicates red shiner in the decline (e.g., Deacon 1988) although the causative mechanism for this shift remains indeterminate. However, the fact that red shiner numbers started to rapidly increase at the same time as their discovery above the Virgin River Gorge in 1984 implicates the Gorge as being a potentially important control historically and possibly in the future on red shiner numbers. Large amounts of habitat exist in and above the Gorge. This gives fish established within and above the Gorge a large recruitment advantage if there is a dispersal pattern of young fish in the downstream direction.

Deacon speculated that red shiner may have passed through the Gorge during the extremely high summer flows of 1993. Flow records at the Hurricane and Virgin gages indicate that summer flows (July and August) in 1983 were much greater (e.g., 50 cfs greater) than the flows at these gages during the summer of 1995 when we observed the Gorge to only dry up for a short time in mid-August. It is clearly possible, therefore, that the Gorge did not dry up during 1983 and that the higher flow conditions made it easier for red shiner to penetrate through the Gorge, particularly if late spring or summer were, or are, important time periods related to red shiner upstream movements. It should be noted, however, that prior to 1983 high summer flows within the Virgin River have existed (e.g., 1967, 1980) without the invasion of red shiner upstream. Regardless, it seems that summer intermittent conditions in the Gorge historically could have produced a relatively effective upstream barrier, especially historically, when it appears that long sections of stream dried up (i.e., 18 miles from Littlefield Springs to the top of the Gorge near the present Red Shiner Barrier). Higher flow conditions now, as a result of more summer irrigation return flows due to Quail Creek Reservoir and wastewater treatment plant return flows, likely have reduced the effectiveness of this natural barrier.

Removal of red shiner from the Virgin River or sections of it will likely remain a major focus in trying to restore native fish populations in the near future. If red shiner can be removed from the upper river, the dry summer and harsh high flow conditions in the Gorge provide a natural barrier to upstream movement of red shiner that should be used to advantage. This barrier could be enhanced by reducing summer flows and/or installing additional manmade barriers similar to the existing Red Shiner Barrier in the Gorge.

The existing Red Shiner Barrier at the top of the Gorge is not ideal. At the present, perennial flows exist immediately below the barrier and even if red shiner can be eradicated upstream, a continual pool of redshiner still would exist adjacent to the barrier and increases the chance of the barrier being breached by red shiner (through natural events or human intervention, e.g.,

people moving fish above the barrier). A more effective barrier could be created in the middle of the Gorge downstream of Cedar Pockets Campground where the annual de-watering occurs (approximately 7 miles of river) by building one or a series of structures. The de-watering would annually purge redshiner from below any constructed barrier creating a buffer zone and increasing the barrier=s effectiveness.

An obvious concern with barriers is their potential effects on native fish movements. The existing Red Shiner Barrier likely traps fish in the upper Gorge in low flow conditions below the barrier. Although better information on fish movements should be obtained through radio tracking, this study suggests that a barrier or series of barriers located downstream of the Cedar Pockets Campground would allow some seasonal use of the Gorge by fish moving upstream from the Littlefield Springs section of river and seasonal use of the upper section of Gorge by native fish moving down from the upper river if the existing Red Shiner Barrier at the top of the Gorge was breached or made passable.

The large number of high quality pools in the lower portion of the Gorge and density of fish in these pool habitats highlight this section of river (and pools in general) as being important habitat particularly during low flows. Pools provide cover in terms of depth and velocity refugia during moderate and low flows. While this study made no attempt to address the quality of microhabitat as a function of discharge, it was apparent that the 40 to 60 cfs of flow that occurred in the Littlefield Springs reach during the summer de-watered conditions, provided relatively good base flow microhabitat. We suspect flows in this range would provide good base flow microhabitat conditions in pools throughout the Gorge and provide decent deeper water habitat conditions in the inherently shallower runs and riffle habitats. In some sections of river upstream of the Top Bridge (RM 54.50) where the river is wider and a somewhat less confined, higher flows may be needed to provide comparable base flow microhabitat quality.

Depending on the management objectives for the Gorge two different and conflicting summer base flow goals could be outlined. If the management objective of the Gorge was to maintain the historic de-watered conditions in the Gorge and/or use the Gorge as a barrier to red shiners, it would be necessary to ensure that during parts of the summer months, flows upstream of the Gorge above the Red Shiner Barrier did not exceed 30 to 40 cfs (and perhaps were much less than this). If the management objective was, however, to enhance seasonal habitat availability and use while facilitating fish movement potential throughout the Gorge, then flows of approximately 60 to 80 cfs would be required at the top of the Gorge. This would ensure perennial flows throughout the Gorge and provide a minimum of about 20 cfs in the middle of the Gorge where flow losses of approximately 40 to 60 cfs occur.

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TABLES

FIGURES

Fish Barrier Below Red Shiner Dam

= Sample Locations

1995 #

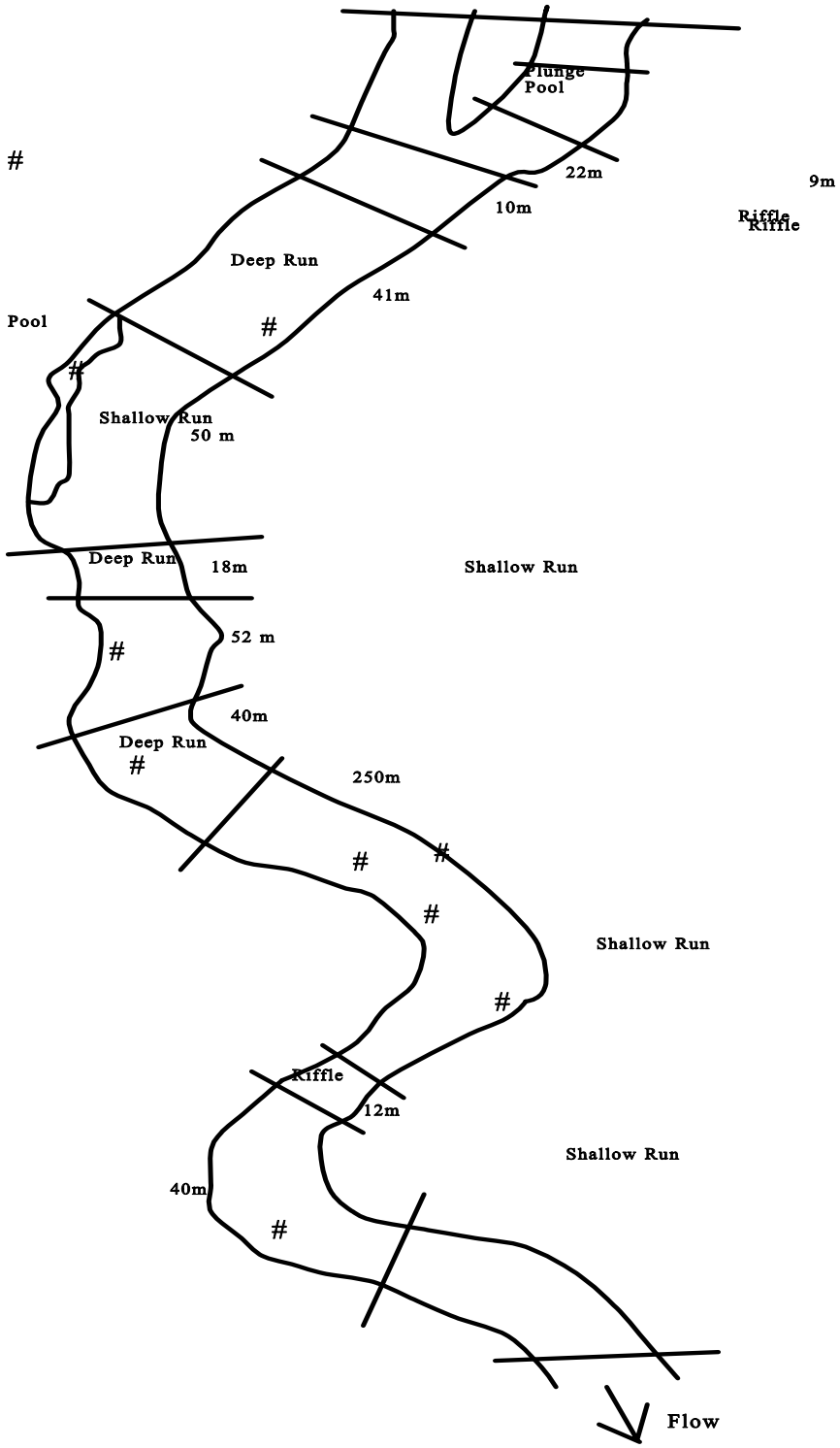


Figure 1. Map of the Virgin River Gor
starting point near Lake Meade.

Figure 1 Continued

Figure 1 Continued

Figure 1 Continued

Figure 2. Linear location of run, riffle, an

Figure 3. Percentage of habitat types in ea

Figure 4. Historic flow data at the Virgin River near St. George gage (1950-1956).

Figure 5. Historic flow data at the Virgin River near St. George and Littlefield Gage (1991-1996).

Figure 7. Example of flannelmouth suck
1995 in one pool at River Mile 49.1 and

Figure 6. Flows at five sites along the Gor

Figure 8. Fish densities along the length
1995, immediately following drying.

Plate 1. *Top left:* Red Shiner Barr
Bottom Left: Shallow sandy run h
Wash section. *Bottom Right:* Dea
desert sucker, flannelmouth sucke

Plate 2. Dead fish in dry section of Gor
sucker, large black bullhead).

Plate 3. *Top left:* Shallow pool and
Littlefield Springs area. *Top Right:*
Pools and snorkeling in upper Little

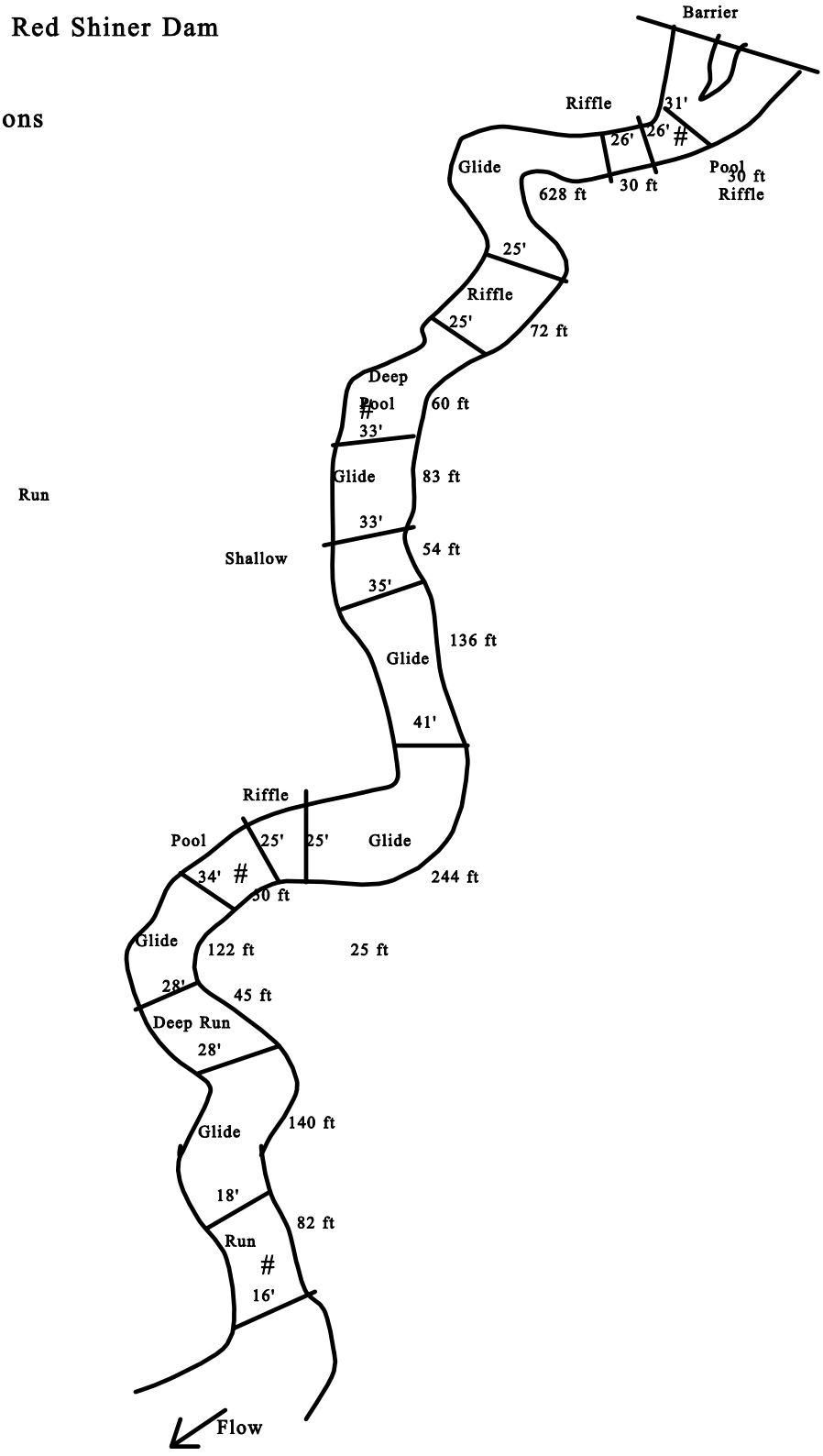
APPENDIX A

Habitat maps of each sampling site with fish sampling locations.

Fish Barrier Below Red Shiner Dam

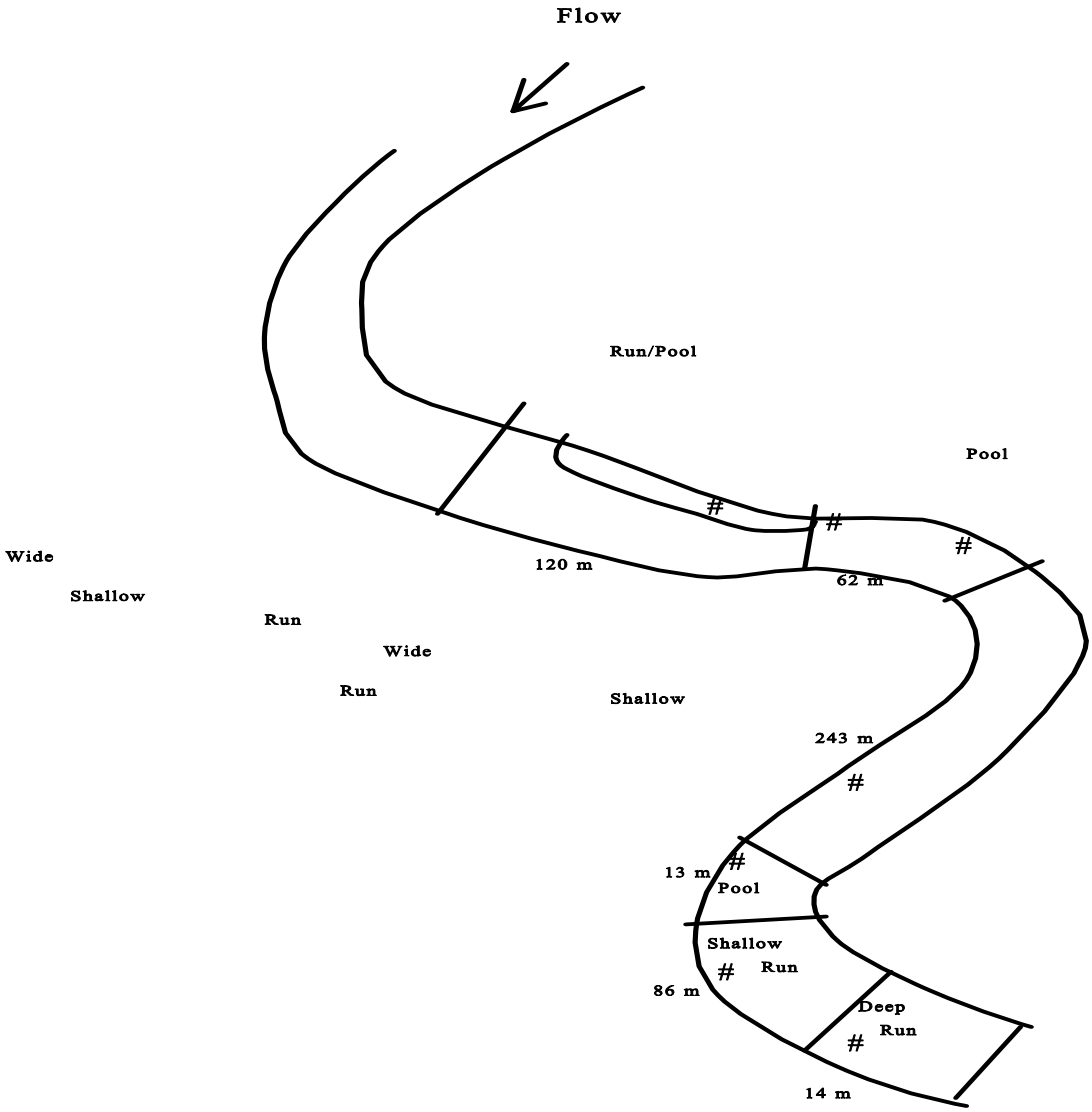
1996

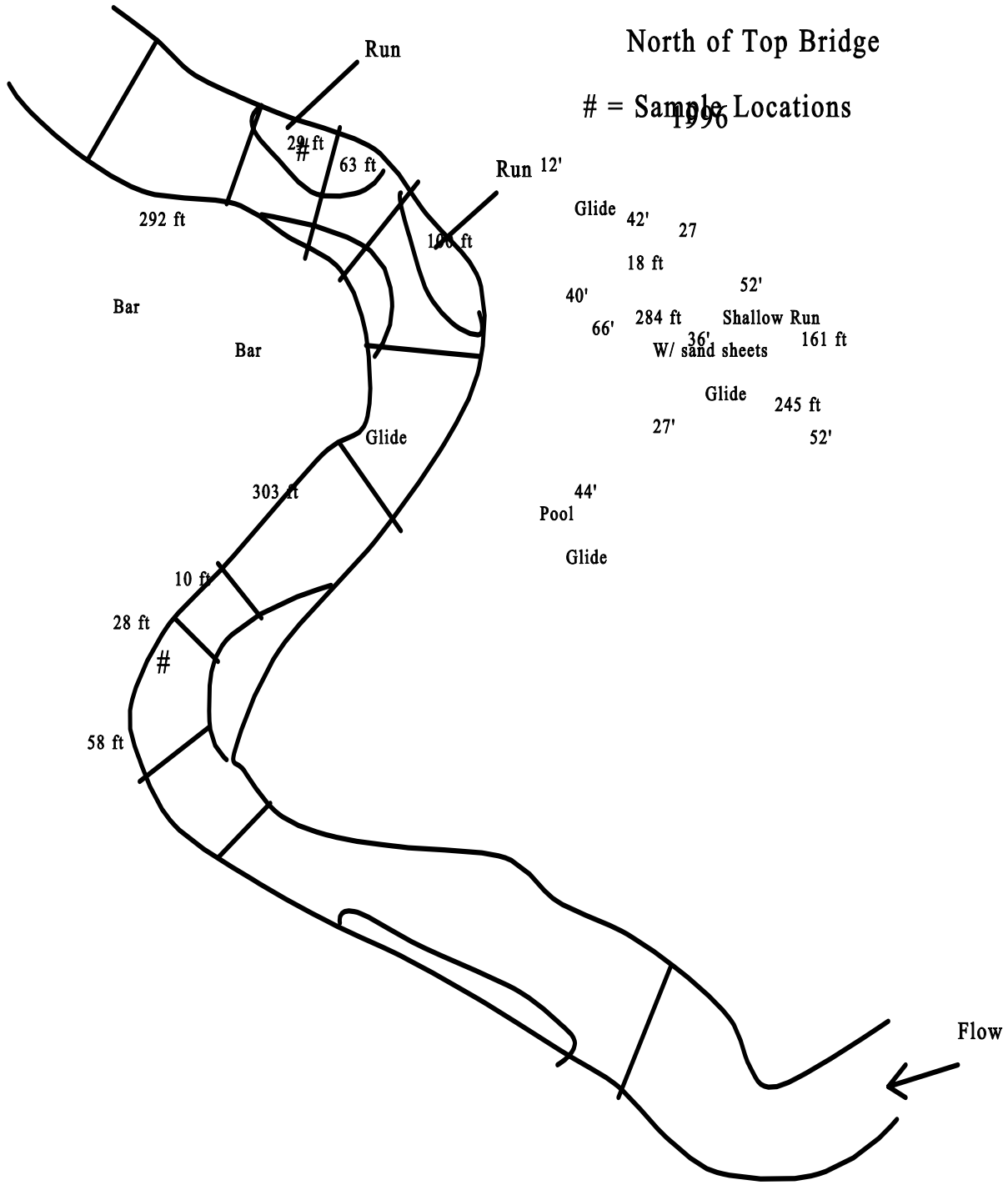
= Sample Locations



North of Top Bridge
1995

= Sample Locations

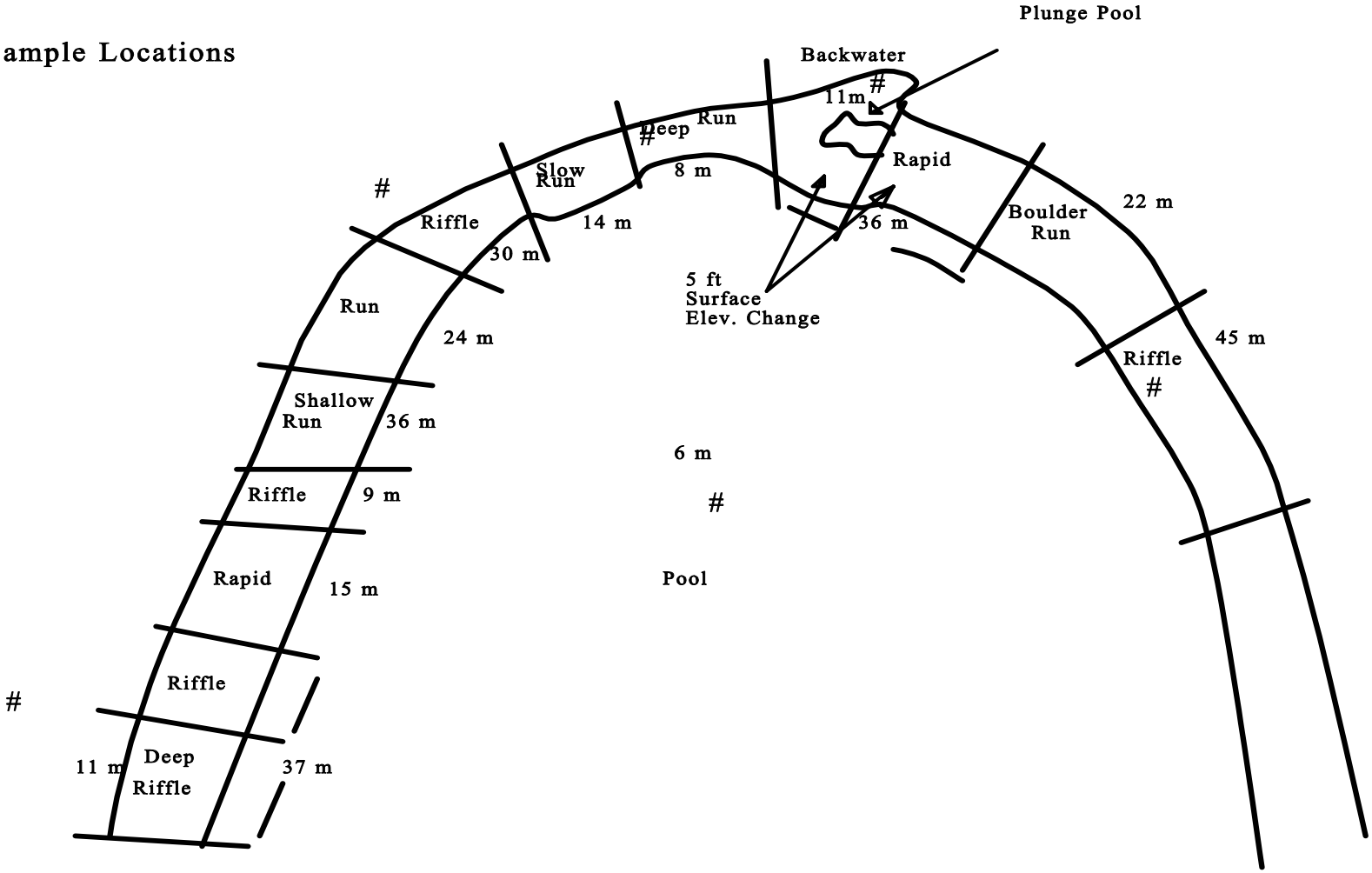


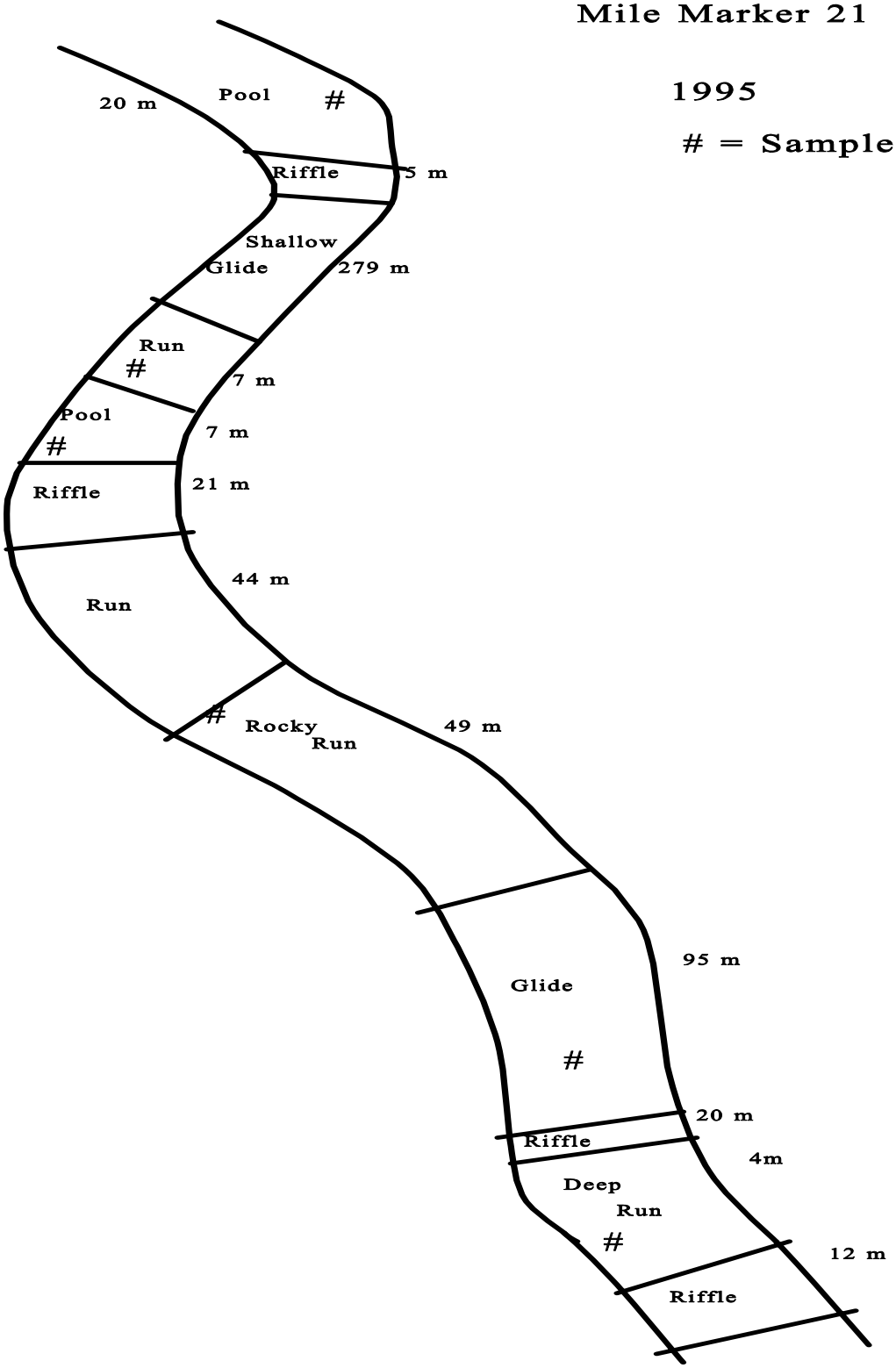

North of Top Bridge
= Sample Locations
1996
Run
Run
12'
Glide
42'
27
18 ft
52'
40'
66'
284 ft
Shallow Run
36'
161 ft
W/ sand sheets
Glide
245 ft
27'
52'
44'
Pool
Glide
292 ft
63 ft
Bar
Bar
Glide
303 ft
10 ft
28 ft
#
58 ft
Flow

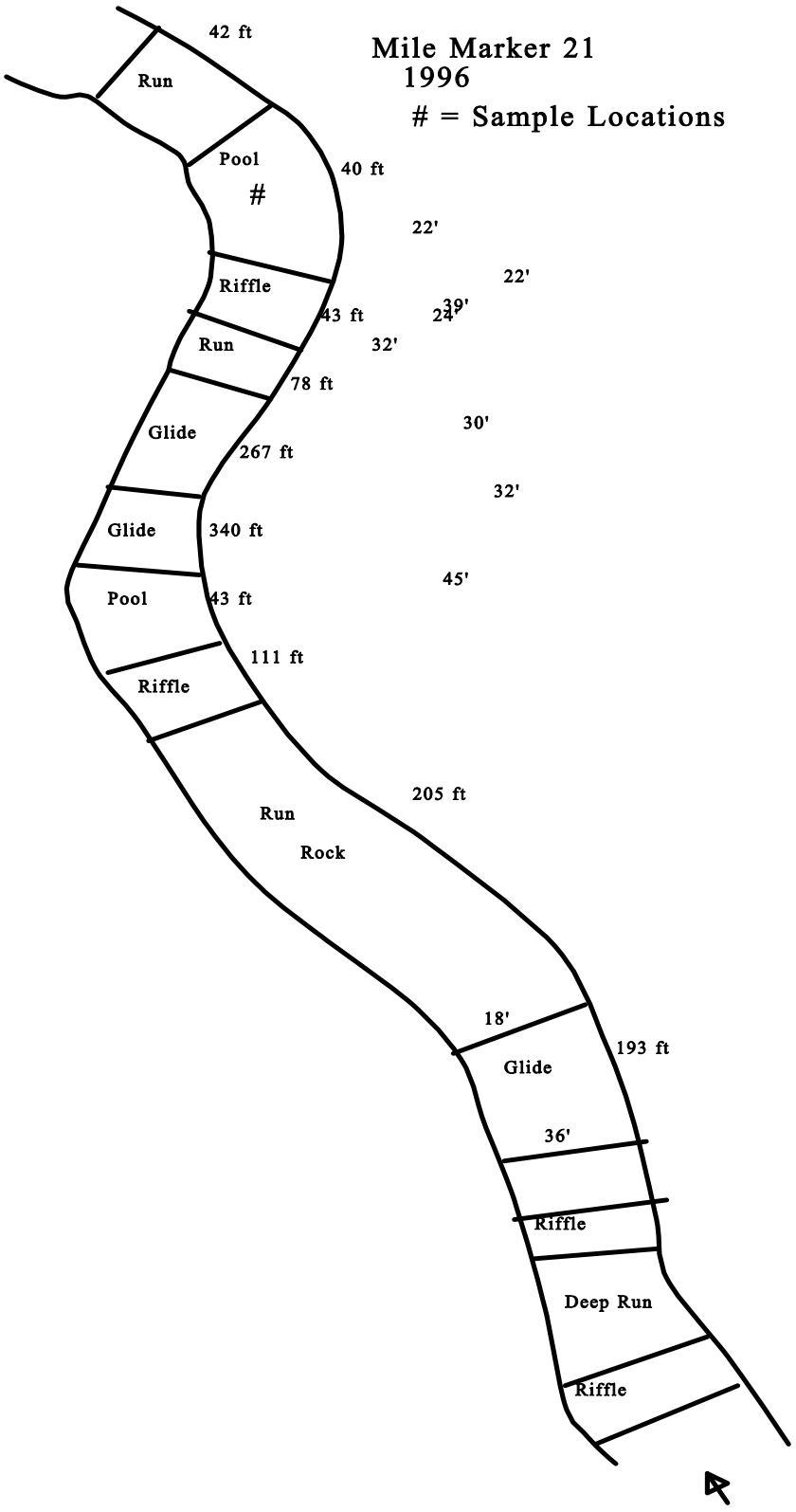
Small Bend Downstream of Top Bridge

1995

= Sample Locations



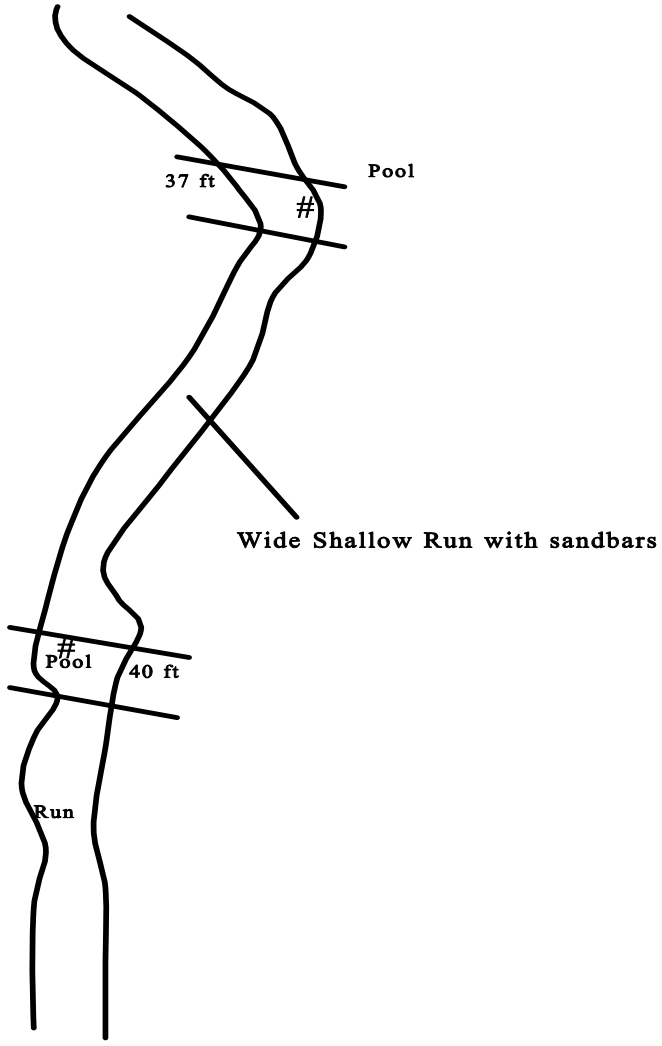

Mile Marker 21
1995
= Sample Locations
20 m
Pool
#
Riffle
5 m
Shallow
Glide
279 m
Run
#
7 m
Pool
#
7 m
Riffle
21 m
44 m
Run
#
Rocky
Run
49 m
95 m
Glide
#
20 m
Riffle
4m
Deep
Run
#
12 m
Riffle

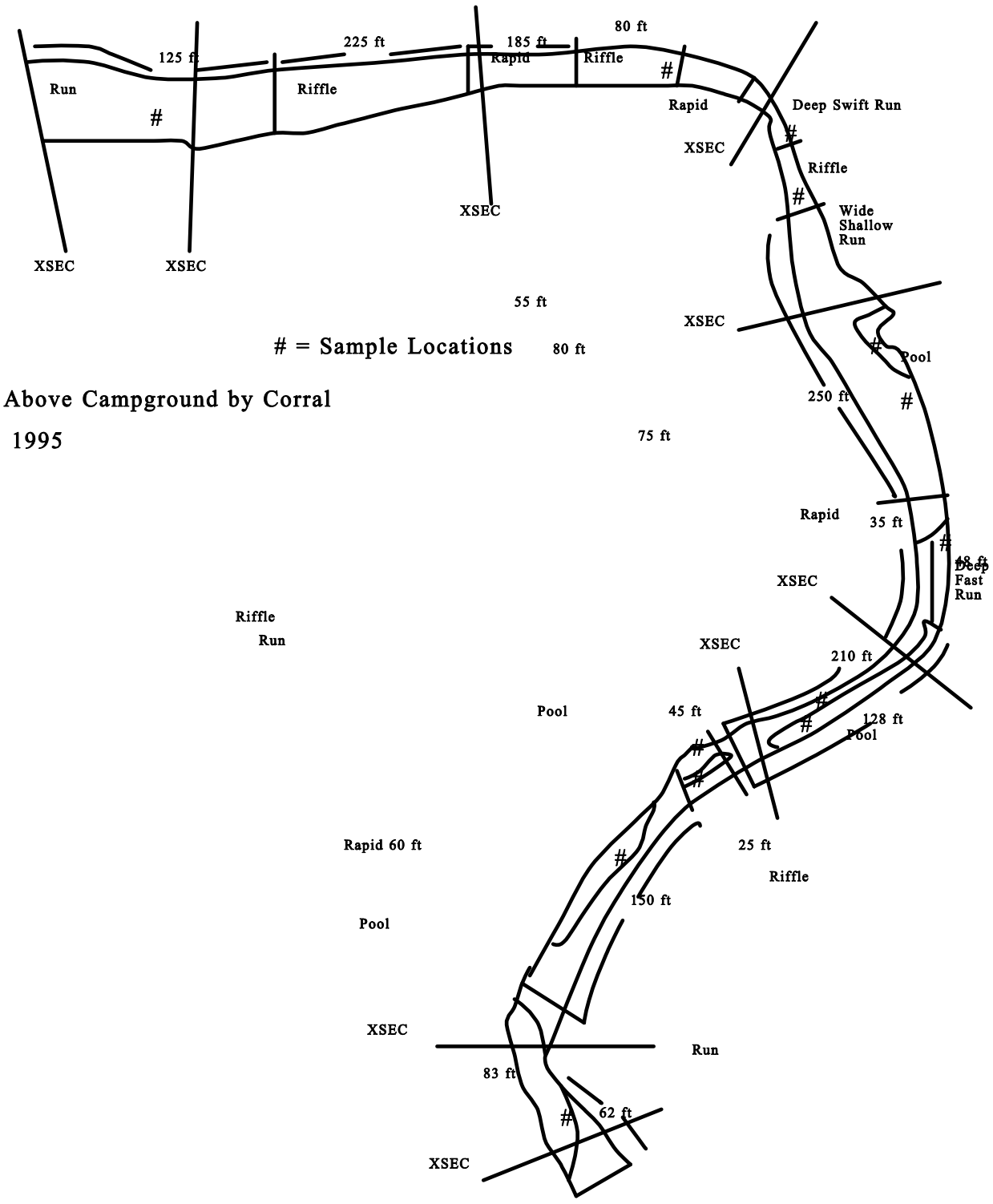

Mile Marker 21
1996
= Sample Locations
42 ft
Run
Pool
#
40 ft
22'
22'
Riffle
39'
43 ft
24'
Run
32'
78 ft
30'
Glide
267 ft
32'
Glide
340 ft
45'
Pool
43 ft
111 ft
Riffle
205 ft
Run
Rock
18'
193 ft
Glide
36'
Riffle
Deep Run
Riffle

Gorge Above Corral

= Sample Locations

1995





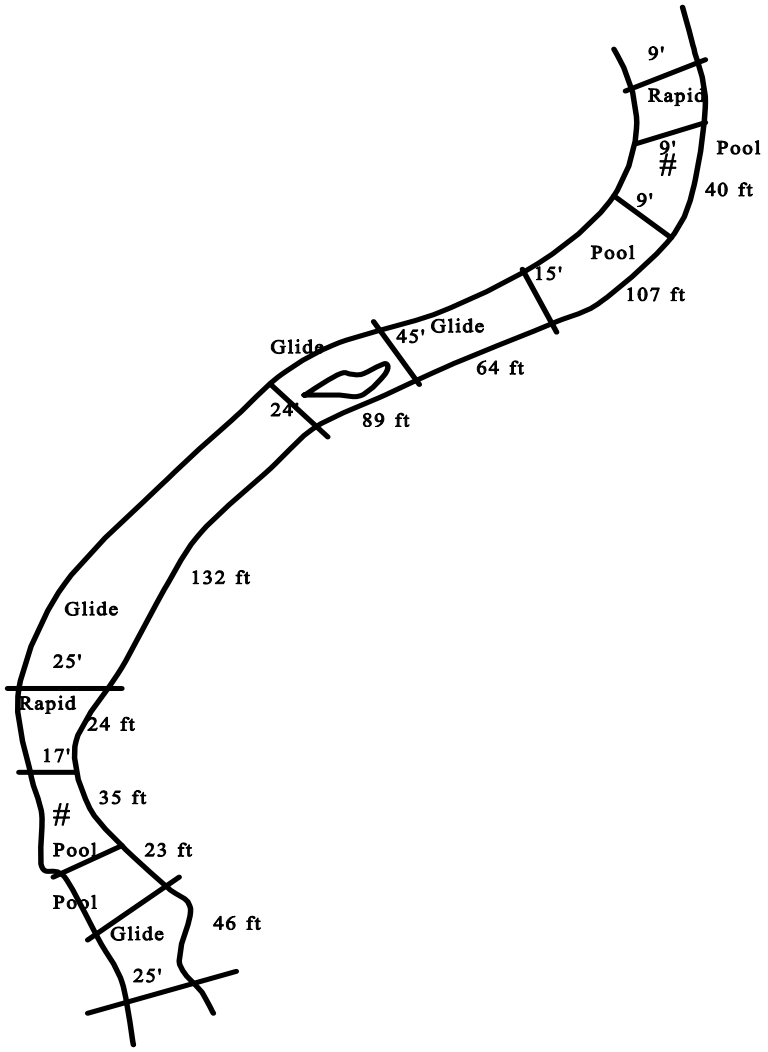
Above Campground by Corral

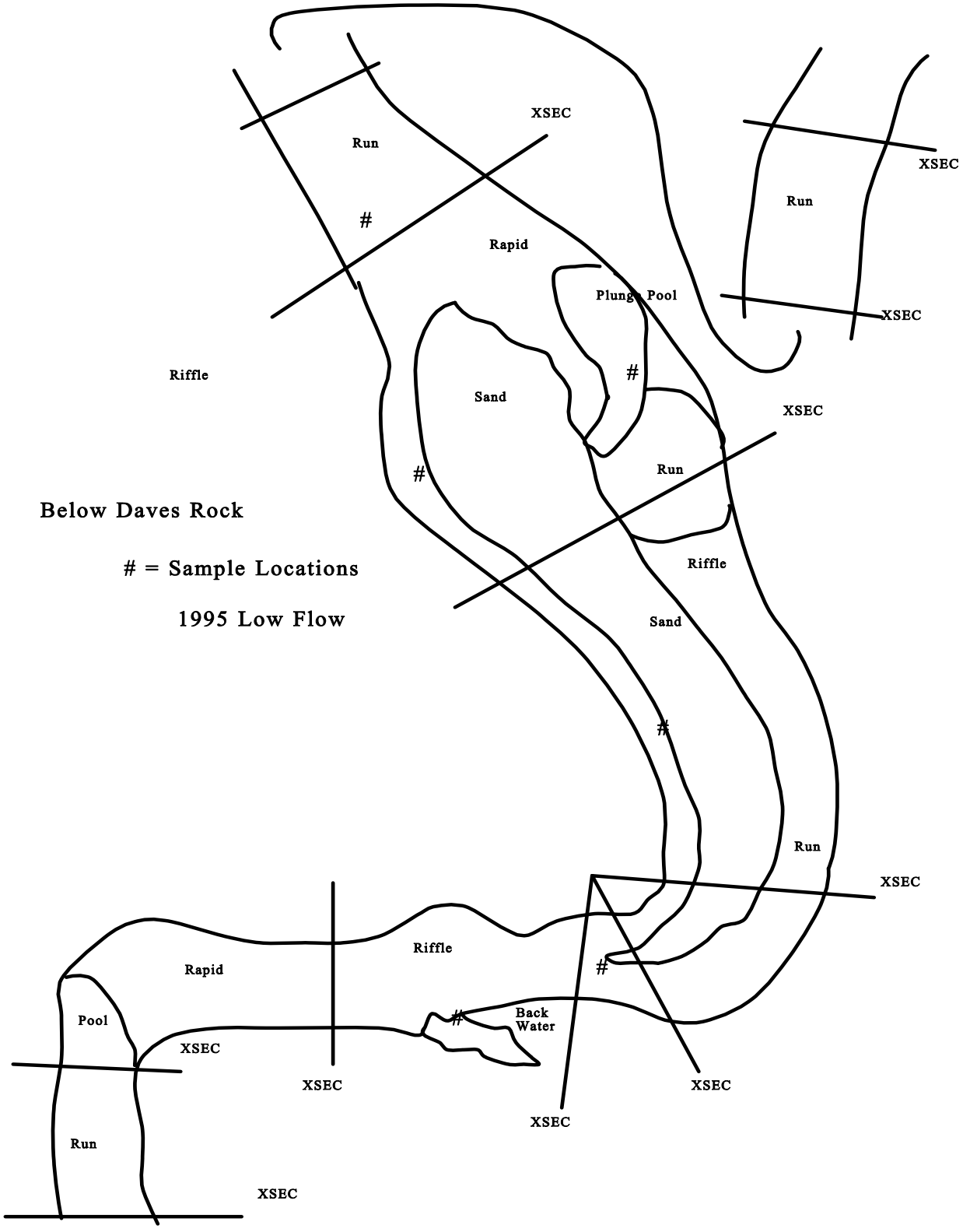
1995

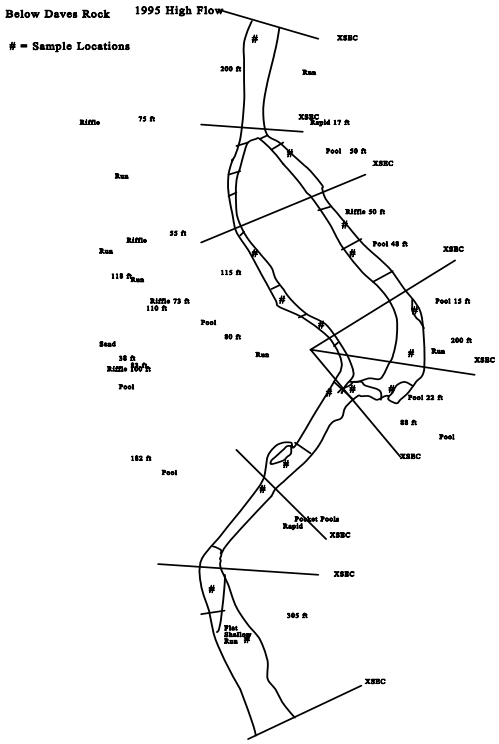
Above Campground by Corral

= Sample Locations

1996

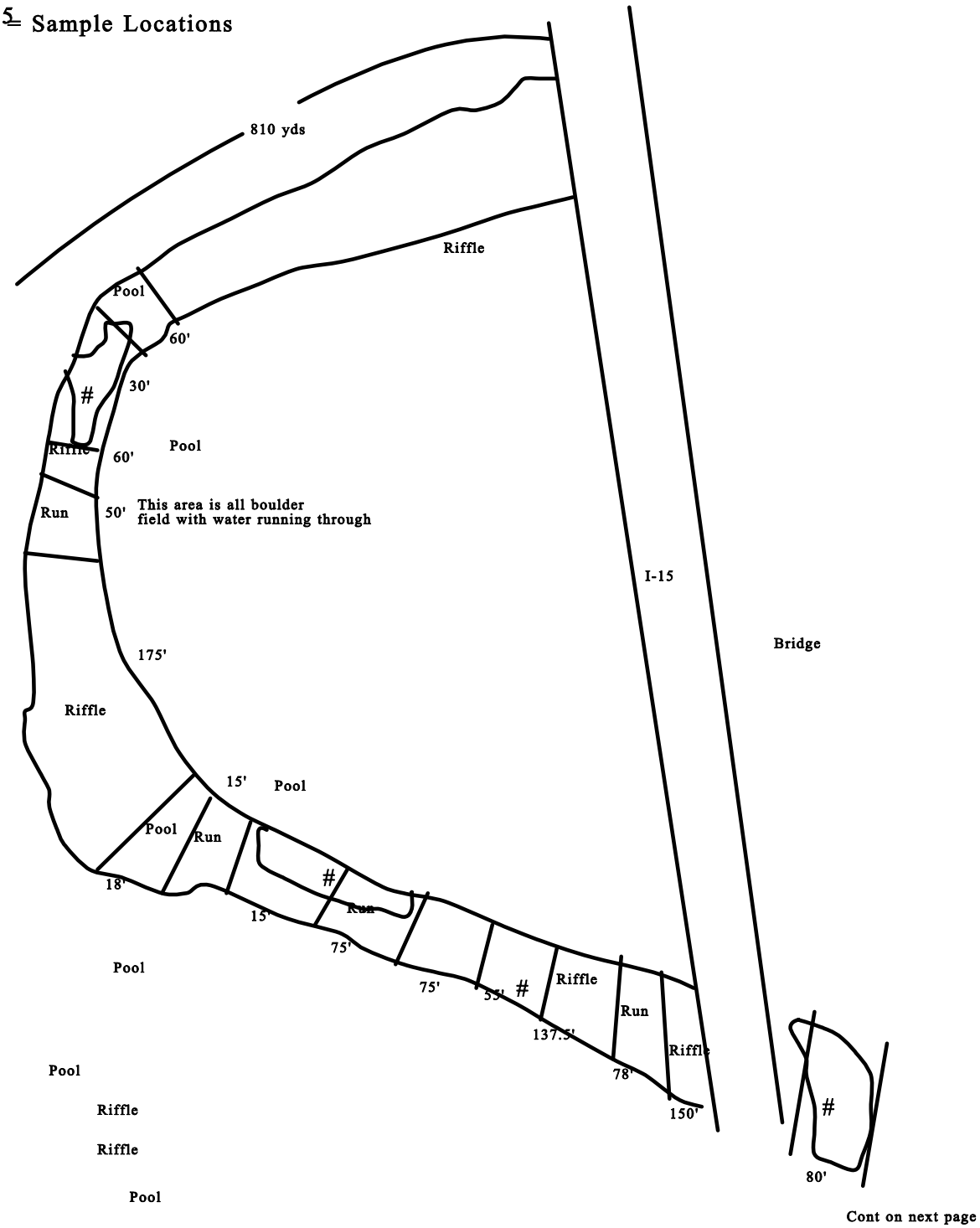


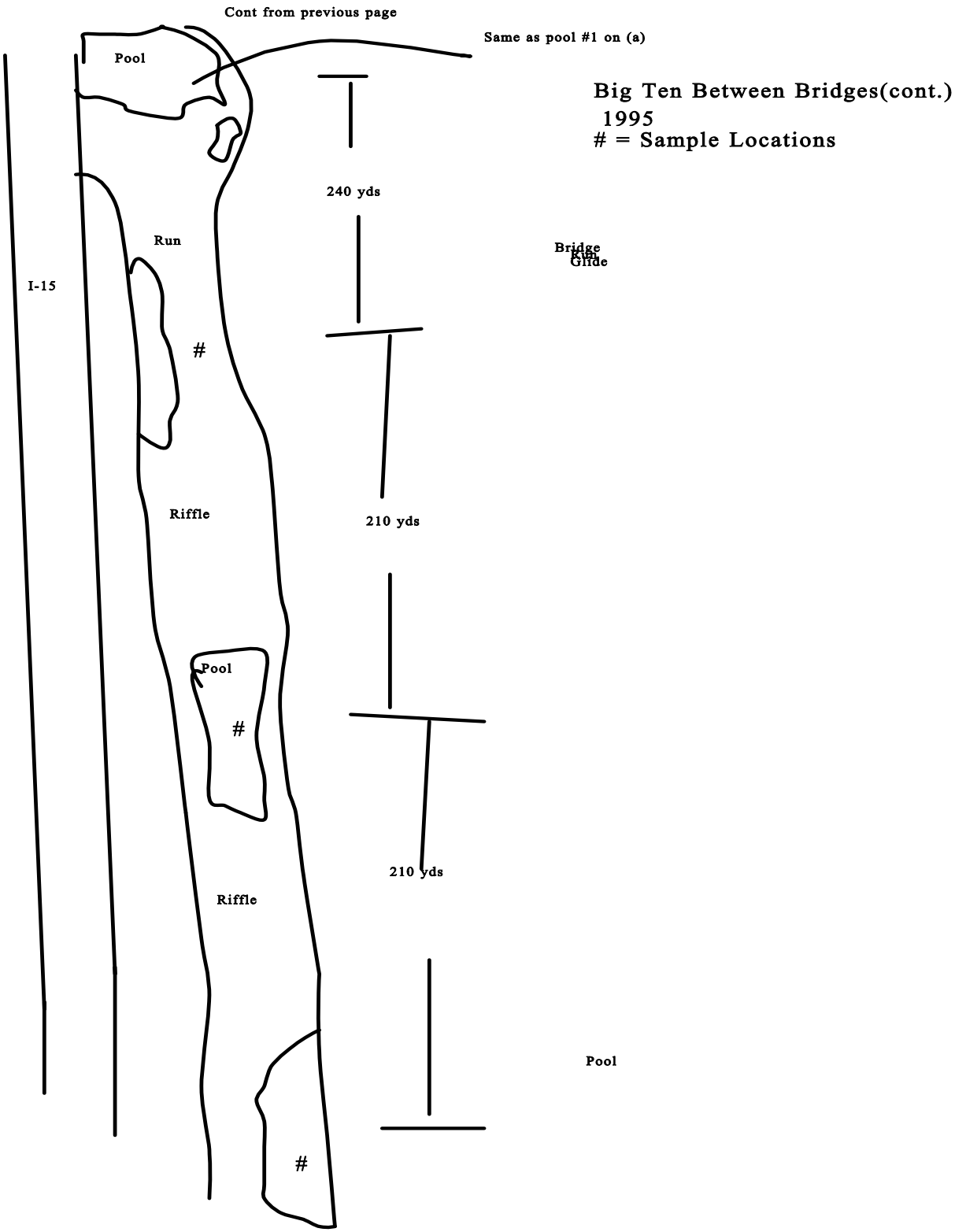

XSEC
Run
#
Rapid
Plunge Pool
XSEC
Run
XSEC
Riffle
Sand
#
XSEC
Run
#
Below Daves Rock
= Sample Locations
1995 Low Flow
Riffle
Sand
#
Run
XSEC
Riffle
Rapid
#
Pool
#
Back
Water
XSEC
XSEC
XSEC
XSEC
Run
XSEC


Below Daves Rock
1995 High Flow
= Sample Locations
XSEC
200 ft
Run
Riffle
75 ft
Rapid 17 ft
Pool 30 ft
Riffle 50 ft
Pool 48 ft
25 ft
Riffle
115 ft
Riffle 75 ft
110 ft
Pool
90 ft
Pool 15 ft
200 ft
Sand
Riffle 100 ft
Pool 22 ft
85 ft
182 ft
Pool
Pokeat Pools
Rapid
305 ft
Flat Shallow Run

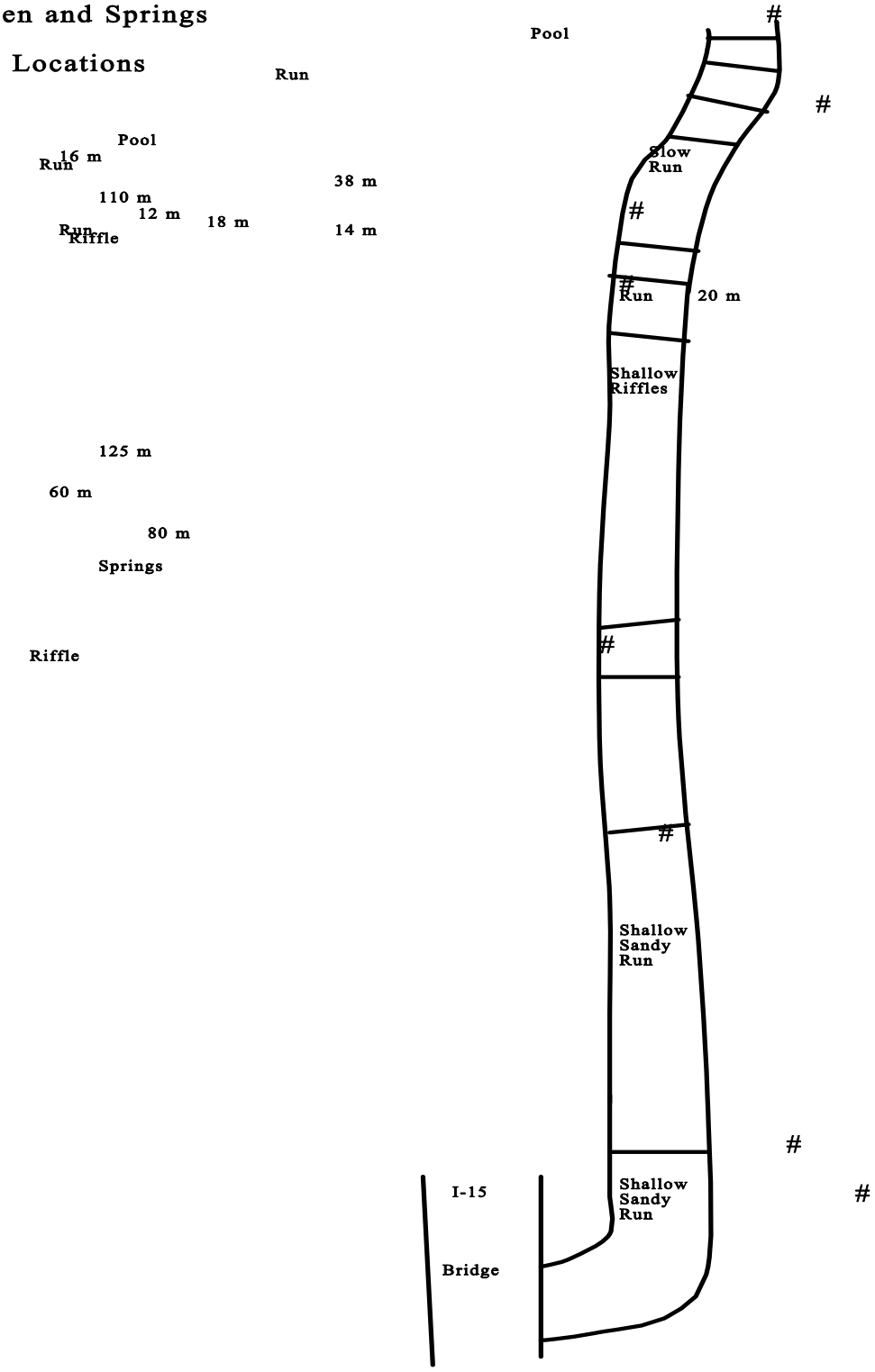
Big Ten Between Bridges (a)

1995 # = Sample Locations



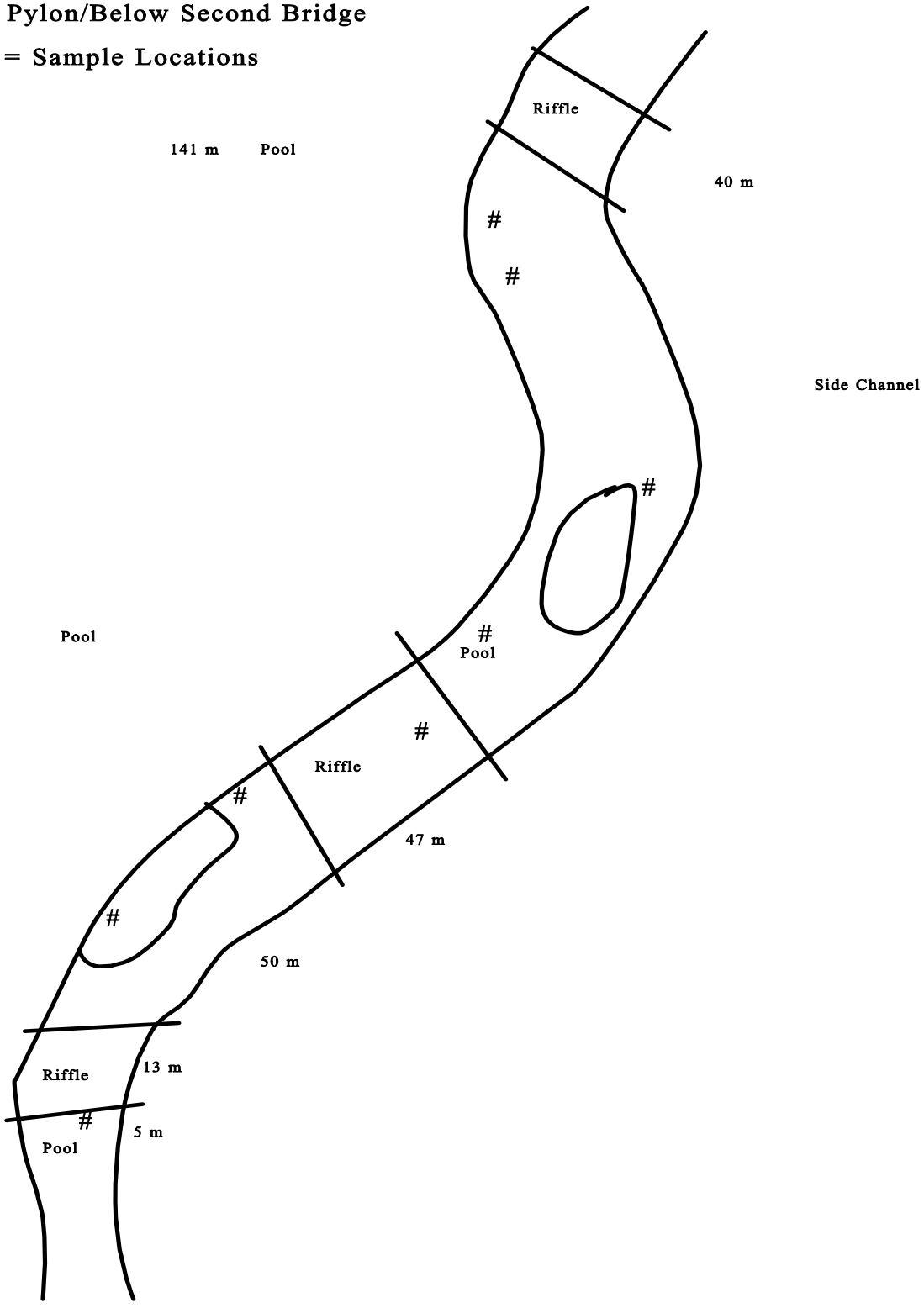

Cont from previous page
Same as pool #1 on (a)
Pool
Big Ten Between Bridges(cont.)
1995
= Sample Locations
240 yds
Run
Bridge
Run
Glide
I-15
#
Riffle
210 yds
Pool
#
210 yds
Riffle
Pool
#

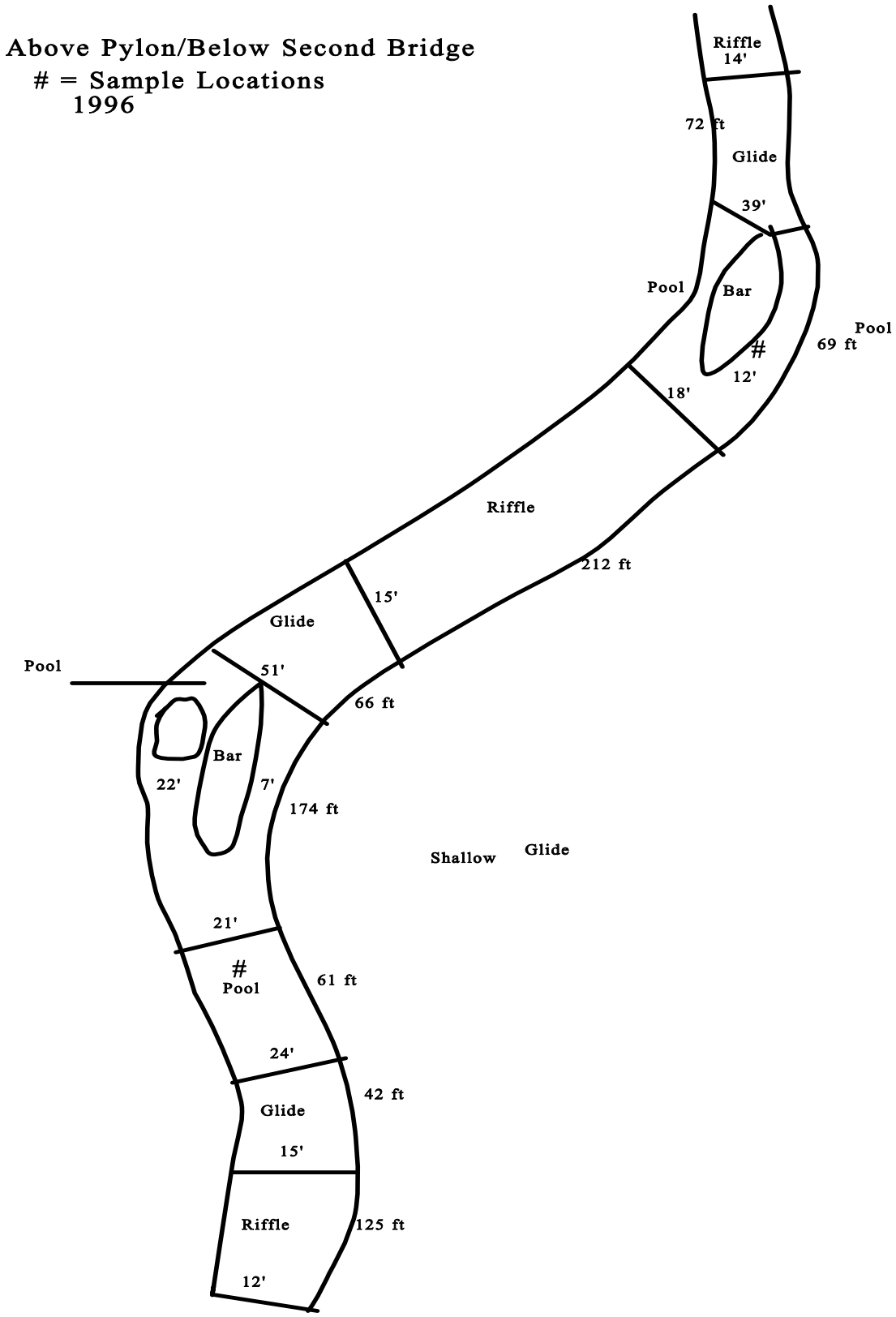
Between Big Ten and Springs
1995
= Sample Locations



Above Pylon/Below Second Bridge

1995 # = Sample Locations

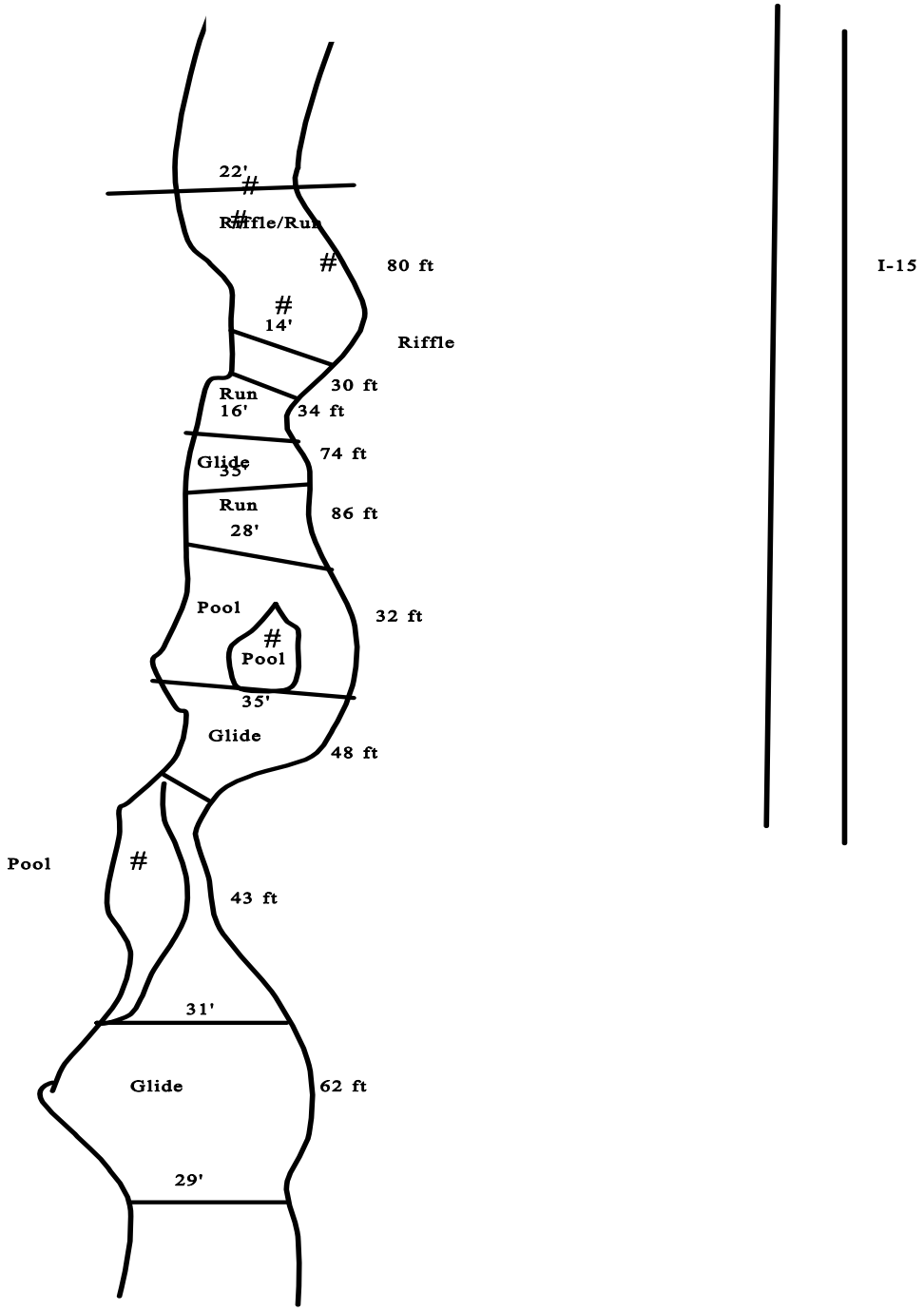



Above Pylon/Below Second Bridge
= Sample Locations
1996
Riffle
14'
72 ft
Glide
39'
Pool
Bar
Pool
69 ft
#
12'
18'
Riffle
212 ft
15'
Glide
Pool
51'
66 ft
Bar
22'
7'
174 ft
Shallow
Glide
21'
#
Pool
61 ft
24'
42 ft
Glide
15'
Riffle
125 ft
12'

Cable Across River
1996

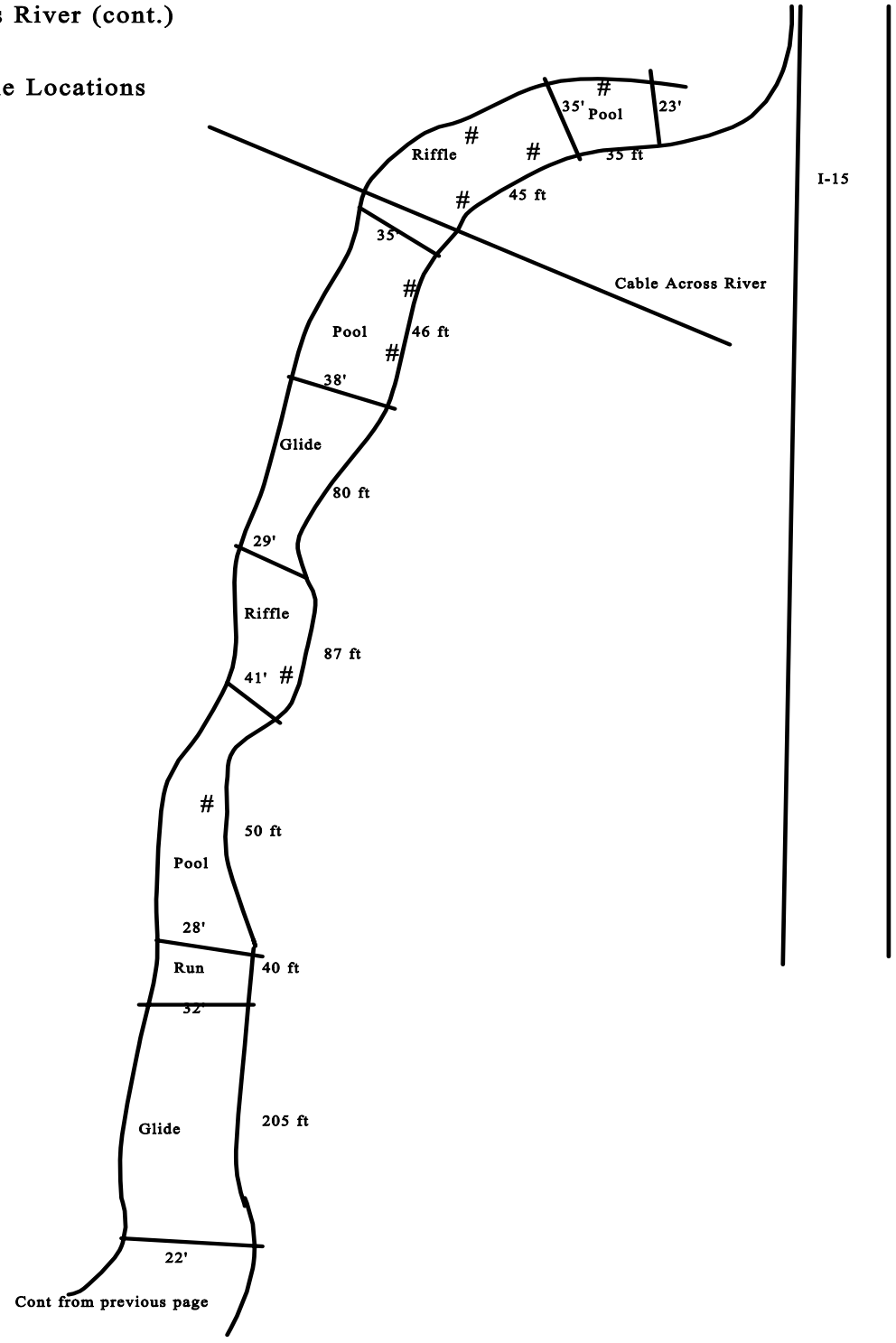
= Sample Locations

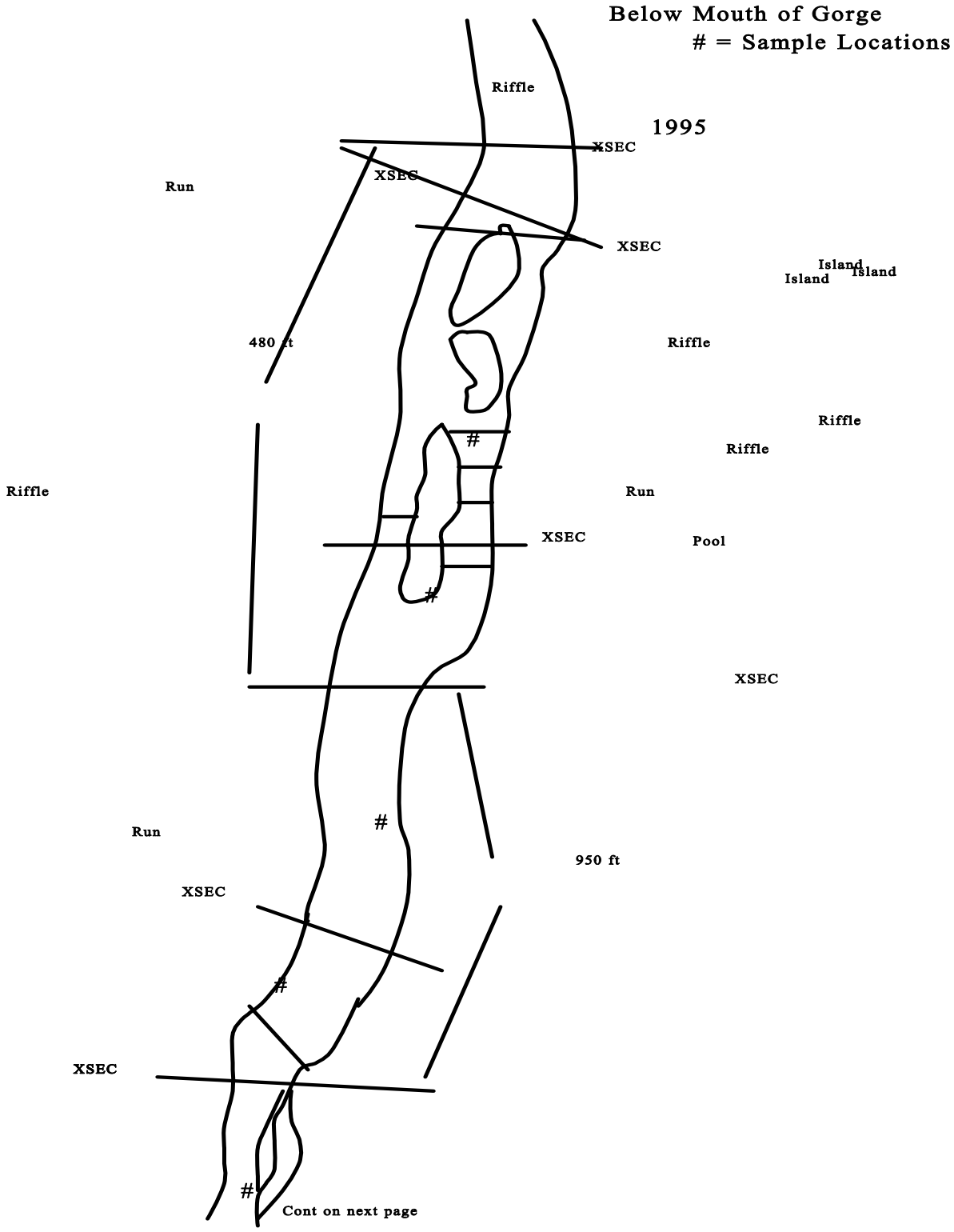
Cont on next page



Cable Across River (cont.)
1996

= Sample Locations

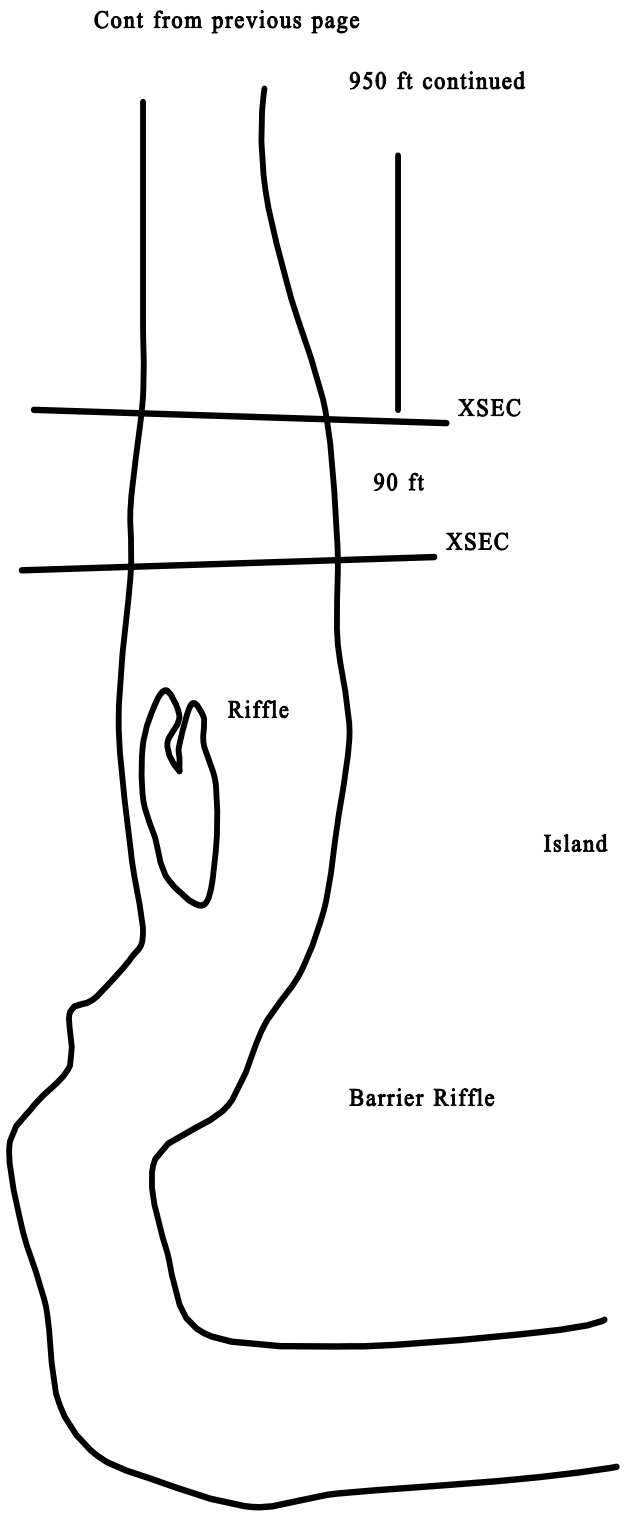


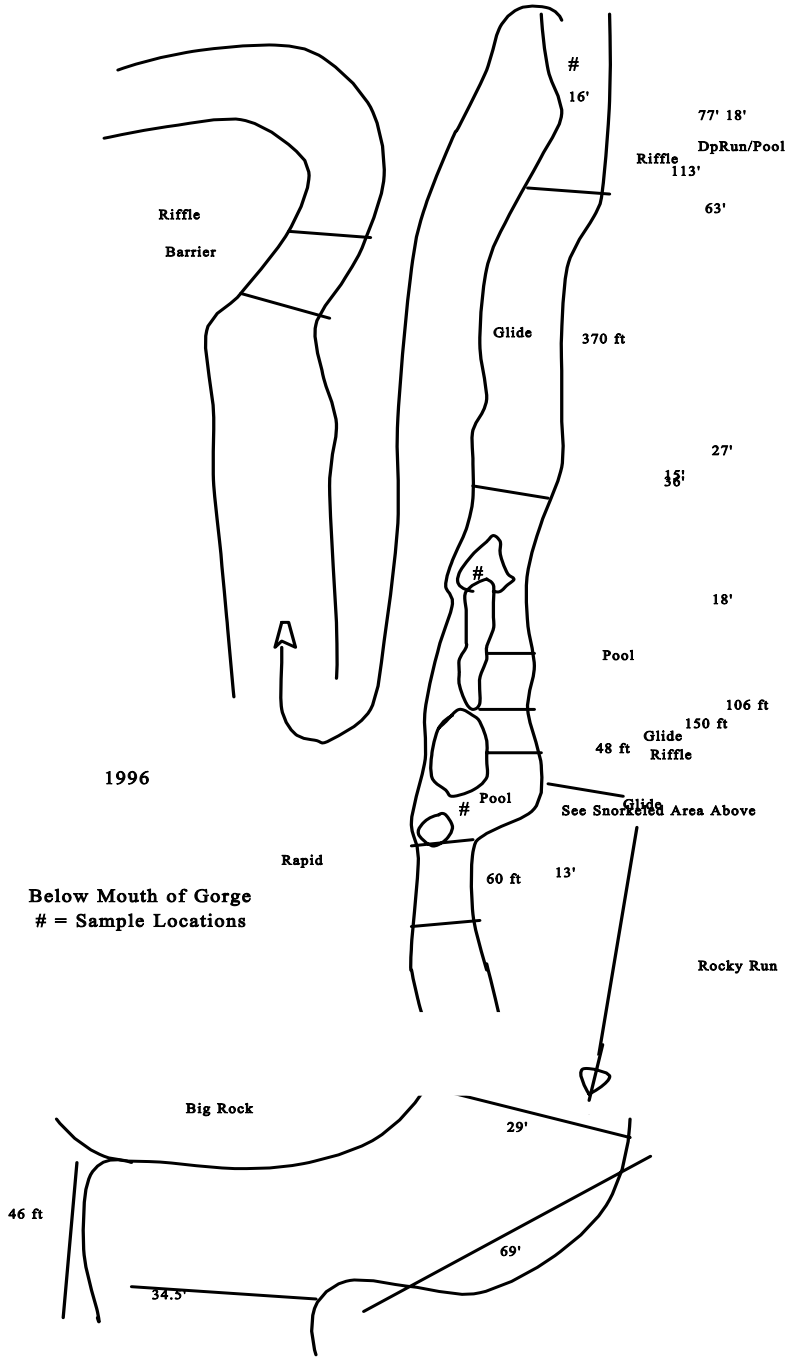

Below Mouth of Gorge
= Sample Locations
1995
Riffle
XSEC
XSEC
Run
XSEC
Island
Island
Island
480 ft
Riffle
Riffle
#
Riffle
Riffle
Run
XSEC
Pool
#
XSEC
#
Run
950 ft
XSEC
#
XSEC
#
Cont on next page

Below Mouth of Gorge (cont.)

= Sample Locations

1995




#
16'
77' 18'
DpRun/Pool
Riffle
113'
63'
Riffle
Barrier
Glide
370 ft
27'
15'
36'
#
18'
Pool
106 ft
150 ft
Glide
48 ft
Riffle
1996
Pool
Glide
See Snorkeled Area Above
Rapid
60 ft
13'
Below Mouth of Gorge
= Sample Locations
Rocky Run
Big Rock
29'
46 ft
69'
34.5'