Rush and Lee Vining Creeks - Instream Flow Study

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1 INTRODUCTION

The State Water Resources Control Board (SWRCB) Order 98-05 established streamflow requirements for Rush, Lee Vining, Parker, and Walker creeks. The annual hydrographs were apportioned to "Instream Flows", i.e., year-around baseflows, and "Stream Restoration Flows", i.e., spring high flow releases and bypass flows intended to simulate snowmelt runoff patterns and functions. Instream flow needs of brown trout in Rush and Lee Vining creeks were identified by instream flow studies conducted in the late 1980's that utilized the Instream Flow Incremental Methodology (IFIM) (CDFG 1991; 1993). Since the implementation of these streamflow requirements the restoration of Rush and Lee Vining creeks has proceeded and has been documented through ten years of monitoring by the SWRCB appointed "Stream Scientists", Bill Trush and Chris Hunter, and their respective scientists. The riparian vegetation and instream habitats are showing definite improvement over time. The brown trout populations are healthy and self-sustaining, although they are not meeting the fisheries termination criteria (as defined in Order 98-05) because of the relatively low number of fish larger than 14" (350 mm). For Rush Creek, the fisheries termination criteria of "size and structure of fish populations" was defined as "fairly consistently produced brown trout weighing 0.75 to two pounds (0.34 to 0.91 kg). Trout averaging 13 to 14 inches (330 to 355 mm) were also allegedly observed on a regular basis prior to the 1941 diversion of this stream". For Lee Vining Creek, the fisheries termination criteria of "size and structure of fish populations" was defined as "to sustain a fishery for naturally-produced brown trout that average eight to 10 inches (200 to 250 mm) in length with some trout reaching 13 to 15 inches (330 to 380 mm)".

The SWRCB Order 98-05, Section 1 b.(2)(a), directed the Mono Basin Stream Scientists to "evaluate and make recommendations based on the results of the monitoring program, regarding the magnitude, duration and frequency of the SRF flows necessary for the restoration of Rush Creek". This evaluation was to occur after two data gathering cycles, but at no less than eight years or more than ten years after monitoring began. The baseflow recommendations also need to be re-evaluated because: (1) in the 22 years since the initial instream flow studies channel morphology has changed, and therefore the relationship between baseflow and fish habitat has changed, (2) we now have a greater understanding of the trout populations and flow conditions that may be limiting recruitment of older age-classes and diminishing survival at key life stages, and (3) necessary assumptions made in past evaluations may not apply today as a result of knowledge gained through recent extensive monitoring.

Monitoring results from the past ten years have allowed the Fisheries Stream Scientists to identify factors that are likely limiting survival, growth rates, and size of large trout in Rush Creek downstream of Grant Reservoir and in Lee Vining Creek downstream of the LADWP diversion. The Rush Creek and Lee Vining Creek Instream Flow Study (IFS) was designed to quantify adult trout holding (primarily winter) and foraging (spring, summer, fall) microhabitat areas over a range of test flows, then assess trout microhabitat area in conjunction with water temperature, fish passage, and riffle hydraulics where trout food resources (benthic macroinvertebrates) are concentrated. The IFS results and flow needs are presented in this Report.

In the Synthesis Report, the Stream Scientists will use the IFS Report results, in conjunction with fisheries, hydrologic, geomorphic, and riparian vegetation data collected over the past ten years of intensive monitoring, to present instream flow recommendations for winter and summer baseflow hydrograph components. The Fisheries Stream Scientists are also submitting four additional reports in August 2009 that will be used to guide flow recommendations.

These four reports are:

- Temperature-Flow Report for Rush and Lee Vining creeks.
- Rush Creek SNTEMP Temperature Model.
- Rush Creek Radio Telemetry-Movement Study Report.
- Pool Survey Report for Rush and Lee Vining creeks.

The Synthesis Report will also be accompanied by an outline of a long-term Monitoring Plan prepared by the Stream Scientists and a revised Grant Lake Operation Management Plan prepared by DWP.

Both Stream Scientists and their respective teams of scientists participated in the Rush Creek and Lee Vining Creek IFS. Chris Hunter and his sub-consultants were responsible for the brown trout components; Bill Trush and scientists from McBain and Trush (M&T) were responsible for the benthic macroinvertebrate (BMI) components. M&T also produced aerial photos, conducted streamflow measurements, digitized habitat polygons, and computed habitat areas.

1.1 Rush Creek Objectives

Based upon our ten years of monitoring the fish population in Rush Creek and our collective experience we have identified two factors that are likely limiting survival and growth (and ultimately the size) of trout in Rush Creek:

1. Lack of suitable winter holding habitat for larger trout, particularly microhabitats with low water column velocities near the stream bottom; and

2. Elevated water temperatures from summer through early autumn, which stress the trout, causing reduced growth rates.

Increasing the abundance of larger brown trout would be accomplished by recommending flows in the Synthesis Report that would increase the amount of suitable winter holding habitat of larger fish. Flow recommendations will also be made to improve summer water temperatures in order to promote better growing conditions (both metabolic rates of trout and productivity of benthic macroinvertebrates).

The general approach followed during the Rush Creek IFS was:

- Utilize data from the 2002/2008 pool/habitat typing surveys, the movement study, and annual fish population sampling to determine study reaches.

- Develop habitat criteria for larger (≥ 350 mm or about 14 inches) brown trout based on a review of the literature and measured criteria from actual locations of radio-tagged large brown trout in Rush Creek collected during the movement study.

- Conduct criteria-based, field habitat mapping to quantify good trout habitat area over a range of test flows to generate habitat-flow relationships.

- Conduct criteria-based, field habitat mapping to evaluate productive benthic macroinvertebrates (BMI) riffle habitat over a range of flows to develop flow-BMI habitat relationships.

- Develop habitat-flow relationship curves to identify habitat needs of adult brown trout.

- Develop habitat-flow relationship curves to identify habitat needs of productive BMI riffle habitat.

1.2 Lee Vining Creek Objectives

A separate IFS plan was developed and implemented on Lee Vining Creek because of specific watershed differences which included:

1. Lee Vining Creek lacks the water storage facility that Rush Creek has (Grant Reservoir), thus LADWP's management of the annual hydrograph is more limited.

2. The Lee Vining Creek channel (downstream of Highway 395) has not yet experienced the same amount of physical recovery, relative to Rush Creek, especially compared to Rush Creek below the Narrows.

3. The Lee Vining Creek channel reach below LADWP's water control structure is steeper than Rush Creek, especially compared to the Rush Creek reach below the Narrows, which has resulted in a much different composition of habitat types. For example, Lee Vining Creek's channel in this reach is dominated by moderate-to-high gradient riffles interspersed with runs/glides and only occasional pools, while Rush Creek's channel below the Narrows has a much higher proportion of pool habitats.

4. In contrast to Rush Creek, elevated summer water temperatures do not appear to be a limiting factor concerning trout growth or survival in Lee Vining Creek.

Based on our ten years of monitoring the fish population in Lee Vining Creek we believe that the lack of suitable winter holding habitat for larger trout (specifically pools containing microhabitats with low water column velocities near the stream bottom directly associated with cover) is the main factor that is likely limiting survival and growth (and ultimately the size) of trout in Lee Vining Creek. Increasing the numbers of larger brown and rainbow trout would be accomplished by recommending flows in the Synthesis Report that would increase the amount of preferred winter holding habitat for larger fish.

In contrast to lower Rush Creek, where reproductive success does not appear to have limited brown trout recruitment during the past ten years, reproductive success of both brown and rainbow trout in lower Lee Vining Creek was often low enough to limit their populations. It appears that the magnitude, duration, and/or rate of flow changes during the spring snowmelt period have periodically caused low reproductive success for both species in lower Lee Vining Creek. Flow recommendations made in the Synthesis Report for Lee Vining Creek will also consider flow regimes that improve the survival of newly emerged brown trout fry and developing rainbow trout eggs and alevins during the spring snowmelt hydrograph period.

The general approach followed during the Lee Vining Creek IFS was to:

- Complete a pool/habitat typing survey in lower Lee Vining Creek to better determine the composition of habitats available for trout and identify potential study reaches.
- Develop brown trout habitat criteria based on literature review and Rush Creek movement study results.
- Conduct criteria-based, field habitat mapping to quantify good trout habitat area over a range of flows to generate habitat-flow relationships.
- Conduct criteria-based, field habitat mapping to quantify productive BMI riffle habitat over a range of flows to develop flow-BMI habitat relationships.
- Analyze habitat-flow relationship curves to identify habitat needs of adult brown trout.
- Analyze habitat-flow relationship curves to identify habitat needs of productive BMI riffle habitat.

Although not considered a high-priority limiting factor to trout production in Lee Vining Creek, the amount of foraging habitat within pools and pocket water habitats was also evaluated during the IFS. Foraging habitat was not considered limited due to the fast growth and good condition factor of brown and rainbow trout in Lee Vining Creek (Hunter et al. 2000-2009). However; if recommendations are made in the Synthesis Report to alter summer baseflows in Lee Vining Creek, an evaluation of changes in potential foraging habitat must be made.

1.3 Brown Trout Habitat Literature to Support Criteria Development

In his comprehensive evaluation of habitat selection by resident brown trout populations native to streams in Norway and Scotland, Heggenes (2002) found that macrohabitats favored by juvenile and adult brown trout were deep and slow-flowing pool areas. More specifically, quoting Heggenes, “On a microscale, however, the niche selected was rather narrow (i.e., brown trout occupied holding positions in slow-flowing water, usually in association with the riverbed)”. When defining “association with the riverbed”, he reported that the holding positions of nearly all brown trout observed during snorkeling surveys were within 0-15 cm (0-6 in) of the stream bottom, regardless of water column depth.

During our 2002 and 2008 pool surveys on Rush Creek, many larger pools with excellent depth and cover components were found to have mean water column velocities ranging from 1.0 to 1.5 ft/s (Hunter et al. 2003). Heggenes found that brown trout essentially avoided areas with water velocities >1.5 ft/s. He further found that very few fish (only 3.9% of those fish observed during his study) selected holding positions where water column velocities were greater than 30 cm/s (1.0 ft/s), even though habitats with water velocities >1.0 ft/s were abundant in the streams he studied. Finally, Heggenes (2002) observed that most brown trout (48.6%) selected holding positions where water velocities ranged from 0-10 cm/s (0-0.3 ft/s).

During the relocation of radio-tagged brown trout on Rush Creek from 2005-2008, nearly all of the fish were found in microhabitats with water column velocities <1.0 ft/s. In fact, 98% of these adult brown trout were relocated where these velocities were equal to or less than 0.7 ft/s. The holding positions of these fish were also associated with various types of cover, but the most consistent habitat variable that was required by these fish was low water velocity near the stream bottom. Furthermore, similar to what was found in the Heggenes (2002) study, most (52.2%) of the relocated brown trout on Rush Creek selected holding positions where water velocities ranged from 0-0.3 ft/s.

About 90% of the radio-tagged adult brown trout on Rush Creek were relocated where water depths were >1.0 ft, which is also similar to the findings of Heggenes (2002). However, nearly all of the Rush Creek fish that were relocated in shallower (<1.0 ft) water were actively spawning (i.e. on or very near redds in riffle areas). Other than during spawning season (Nov-Jan), water depths at nearly all (about 98%) of the sites occupied by relocated fish exceeded 1.0 ft.

Heggenes (2002) also noted that the brown trout populations that he studied clearly exhibited "size structured habitat use"; i.e., there was a distinct pecking order wherein the largest fish occupied the most suitable habitats and progressively smaller fish were forced to occupy increasingly less suitable sites. Again, quoting Heggenes (2002), "Smaller fish more often held positions close to the bottom in slower, shallower water with less cover, typically along the stream banks". During ten years of electrofishing and snorkeling surveys on Rush Creek, similar hierarchical habitat use by brown trout has been noted, with juvenile fish primarily occupying the shallower areas of runs and pools, while the majority of fry were found in riffle habitats and along the margins of pools and runs (Hunter et al. 2000-2009).

Similar brown trout habitat preferences have also been reported by a number of other researchers when focal point velocities were measured. Adult brown trout's preference for direct overhead cover was another consistent theme found throughout the published literature.

Cunjak and Power (1986) examined habitat utilization by brook trout (*Salvelinus fontinalis*) and brown trout during three winters of underwater observations in the Credit River, located in southern Ontario. In winter, at sites of sympatry, brown trout occupied greater focal point water depths than brook trout; however both species had similar average focal point water velocities (0.18 ft/s in the Spring tributary and 0.56 ft/s in the North Branch). At all sites, and for both age groups and species, there was a strong preference for positions beneath cover. Relative to summer, trout positions in winter were characterized by slower water velocities and greater overhead cover. In winter, most trout were in aggregations, usually in pools beneath cover and close to point sources of groundwater discharge. Gregarious behavior appeared to increase as water temperatures decreased; no such relationship was evident in the summer. Specific strategies for overwintering varied between sites and age groups but generally conformed to the theory of energetic cost minimization for position choice.

Greenberg et al. (1996) studied the microhabitat preferences of brown trout and grayling in the upper portion of the River Vojmån, northern Sweden in 1990-1993. Summer microhabitat preference was quantified for open water fish during the day and at dusk and for fish residing under stones during the day. In total, measurements were made for 665 trout and 230 grayling, ranging in size from 2.5 to 50 cm total length. Relationships were found between most microhabitat variables and fish length. All size classes of brown trout preferred waters with low current velocities, generally less than 10 cm/s (0.33 ft/s). However, medium to large sized trout did not show as strong avoidance of fast currents as smaller trout.

Raleigh et al. (1986) included an extensive literature review of brown trout habitat preferences during their development of habitat suitability index models and instream flow suitability curves for brown trout. In describing "fish nose" velocities, Raleigh et al (1986) stated that velocity preferences of adult brown trout in other studies ranged from 0.0 to 0.7 ft/s for resting fish and 0.5 to 1.5 ft/s for feeding. Cover was considered an essential component of viable trout streams and adult brown trout seek cover more than any other trout species (Raleigh et al. 1986). In winter, brown trout showed a strong hiding or cover response and sought deep, low-velocity areas associated with cover (Hartman 1963 in Raleigh et al. 1986).

1.4 Rainbow Trout Habitat Considerations

Unlike Rush Creek, rainbow trout are a significant component of the Lee Vining Creek trout population, comprising from 10% to 40% of the total standing crop estimates over the past ten years (Hunter et al. 2000-2009). Rainbow trout have slightly different habitat preferences than brown trout that were considered when developing criteria. Although we have not conducted extensive field work with rainbow trout in regards to micro-habitat preferences, a review of published scientific literature was conducted. In regards to velocity criteria, a majority of the published studies focused on average water column velocities. However; several papers/studies were found that examined focal point velocities, that is, the velocity of where fish were observed in an undisturbed state.

Adams (1994) reported a preferred focal point velocity of 0.6 ± 0.2 ft/s for 155-175 mm rainbow trout in the Little Weiser River in Idaho. No season was specified as to when these measurements were taken. For summer foraging of rainbow trout ≥120 mm in three western Sierra streams, a preferred focal velocity of 0.5 ± 0.4 ft/s was reported by Baltz and Moyle (1984).

During an instream flow study in the Pit River, Vondracek and Longanecker (1993) reported that the largest rainbow trout occurred in slow, deep areas of pools, where they moved slowly without orientation to flow and were not observed feeding, whereas small fish generally faced upstream and fed in all habitat types. This study also reported that rainbow trout apparently sought shelter in interstitial spaces in the substrate of runs and riffles during the day in early winter. Foraging forays were directed up in the water column at velocities similar to the mean water column velocities at holding positions. Vondracek and Longanecker (1993) also reported focal point velocities for rainbow trout ≥120 mm in length for three habitat types: in pools = 0.9 ft/s ± 0.6 ft/s, in runs = 0.9 ft/s ± 0.5 ft/s, and in riffles = 1.1 ft/s ± 0.7 ft/s. Rainbow trout were the most abundant species in 76% of the population survey stations. Other species that might have influenced microhabitat selection by rainbow trout were uncommon.

The seasonal habitat requirements of redband trout (a sub-species of rainbow trout native to the Columbia River basin) in tributaries of the upper Kootenai River drainage in Montana were investigated during 1997 and 1998 (Muhlfeld et al. 2001a; Muhlfeld et al. 2001b). During summer juvenile (36-125 mm) and adult (> 126 mm) redband trout preferred deep microhabitats (> 0.4 m) with low to moderate velocities (< 0.5 m/s or 1.6 ft/s) adjacent to the thalweg. Conversely, age-0 (< 35mm) redband trout selected slow water (< 0.1 m/s) and shallow depths (< 0.2 m) located in lateral areas of the channel. Age-0, juvenile and adult redband trout strongly selected pools and avoided riffles; runs were used generally as expected (based on availability) by juveniles and adults and more than expected by age-0 redband trout. At the macrohabitat scale, a multiple regression model indicated that low-gradient, mid-elevation reaches with an abundance of complex pools are critical areas for the production of redband trout. Mean reach densities ranged from 0.01-0.10 fish/m^2.

Fall and winter habitat use and movement were investigated by using radio telemetry in which 26 adult redband trout were implanted with radio transmitters and relocated twice a week (Muhlfeld et al. 2001a). During the fall and winter period, adult redband trout occupied small home ranges and found suitable overwintering habitat in deep primary pool habitats with extensive amounts of cover in headwater streams. As water temperatures dropped in November and December, the proportional use of primary pool habitat increased by 29%. Most of the documented movements of tagged redband trout into primary pools were those fish initially captured in runs, pocket water and lateral pools. Sedentary fish commonly remained in the primary pool habitats where they were originally captured, tagged and released. Primary pools were relatively deep and contained extensive amounts of cover, with a mean percent of total cover of 60% (range 30-100%). Large woody debris covered an average of 27% of the pool surface area (range 0-70%). Muhlfeld et al (2001a) suggested that maintaining deep pools with complex cover is critical for the conservation of native redband trout in the upper Kootenai River drainage.

Habitat preference criteria for brown and rainbow trout were also reported for eastern Sierra Nevada streams by Smith and Aceituno (1987). Their work involved snorkel observations of trout followed by velocity, depth and distance-to-cover measurements made at the focal points where trout were observed in an undisturbed state. Their results suggest that rainbow trout often occupy slightly faster velocities than brown trout; however they were uncertain if this was a preferred difference or if rainbow trout were displaced to higher-velocity areas by more dominant brown trout. In all of their study streams brown trout were, by far, the more abundant trout species.

For summer foraging, rainbow trout will position themselves in lower velocity areas next to shear zones of faster moving water. Campbell and Neuner (1985) reported, “Trout were observed immediately adjacent to fast moving water, but almost always at a station where the current velocity was reduced. Typical stations were in lee of boulders or submerged objects in flowing waters or along shear-lines in pool environments".

1.5 BMI Literature Review and Habitat Requirements

A productive and diverse benthic macroinvertebrate (BMI) community is important for maintaining stream ecosystem integrity under a regulated flow regime (Orth 1987, Gore et al. 2001, Jowett 2003). Benthic macroinvertebrates transform allochthonous (e.g., leaf litter) and autochthonous (e.g., benthic algae) material into an energy source that higher trophic levels consume (Hynes 1970, Orth and Maughan 1983). With exception of predation on young-of-year and juvenile trout by larger adult trout, trout generally derive most prey from drift of benthic macroinvertebrates (Elliot 1973, Murphy and Meehan 1991, Hunter 1991, Jowett 2003) . However, relative contributions of terrestrial insects such as grasshoppers, ants and beetles are unknown in Rush and Lee Vining creeks, which in many systems are seasonally important food sources that can provide a significant percentage of a trout's annual energy intake (Saunders and Fausch 2007).

Many instream flow practitioners have recognized that habitat requirements of benthic macroinvertebrates should be considered alongside other ecosystem functions in assessing instream flow needs (Gore and Judy 1981, Orth 1987, Degani et al. 1993, Gore et al. 2001, Jowett 2003, 2007, Wills et al. 2006). Flow regulation may impact benthic invertebrates because species diversity is highest in riffles, and riffle habitat is the most sensitive to flow reductions (Hynes 1970, Ward 1976, Ward and Stanford 1979). Orth and Maughan (1983) show significant reduction in invertebrate biomass between two sampling seasons, apparently related to reduced depths and velocities in riffles resulting from a drought. Wills et al. (2006) found that the density of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa was reduced significantly in an experimental treatment zone of a small Michigan stream when 90% of the water was diverted as compared to density at baseflow or when flow was reduced by 50%. Positive correlations were observed by McFadden and Cooper (1962) between stream productivity and production, standing crops, and growth of brown trout. In New Zealand, Jowett (1992a from Jowett 2003) found that BMI abundance was more highly correlated with adult brown trout abundance than any other single factor, and was also correlated with juvenile brown trout abundance.

Gore and Judy (1981) recommend "a stream-flow management strategy, then, must include a flow to maintain invertebrates (often the primary fish food source) in order to assure optimum fish production." Providing adequate holding and forage habitats for trout populations does not ensure adequate habitat for other aquatic organisms (Gore and Judy 1981, Orth and Maughan 1983, Gore et al. 2001, Doledec et al. 2007). However, riffles supporting productive BMI habitat, in association with adult trout foraging habitat, may improve trout productivity, growth, and ultimately survival (Hunter 1991).

Linking stream discharge to benthic invertebrate productivity is the most direct strategy for determining instream flow needs for invertebrates, but secondary productivity (expressed in units of biomass of macroinvertebrates per unit surface area per unit time, e.g., g/ft^2/day) is difficult to measure. Even if secondary productivity were measured, a more daunting task would remain: establishing a quantitative relationship between macroinvertebrate productivity, fish populations, and stream-flow. Although easier to measure than secondary productivity, increases in invertebrate biomass, diversity, and drift rate also would be difficult to correlate with increases in fish biomass (Gore 1989). As with trout habitat studies, a more feasible strategy, albeit less direct, is to assess the effects of instream flows on BMI habitat abundance; riffle habitat abundance is the most sensitive to flow reductions (Hynes 1970, Ward 1976, Ward and Stanford 1979).

Numerous studies have demonstrated that hydraulic variables (water depth and velocity), stream substrate, and water temperature are primary variables determining BMI habitat suitability, invertebrate densities and productivity, and species diversity (Statzner et al. 1988, Beisel et al. 1998, Corkum 1989, Degani et al. 1993). Others have demonstrated statistically significant relationships between benthic invertebrate species diversity (richness and abundance) and habitat suitability based on measured hydraulic variables (Gore and Judy 1981, Orth and Maughan 1983, Gore 1989, Degani et al. 1993, Doledec et al. 2007, Fjellheim 1996, Merigoux, and Doledec 2004, Wills et al. 2006). Benthic invertebrate densities have also been related to more complex substrate and hydraulic parameters such as Froude number, Reynolds number, and boundary layer terms (Trush 1979, Orth and Maughan 1983, Statzner 1988, Jowett et al. 1991, Merigoux and Doledec 2004, 2009). The implication with regard to Froude number is that invertebrate abundance increases as velocity increases, and decreases as the square root of the depth increases (Jowett 2003).

Gore and Judy (1981) developed habitat suitability criteria based on depth, velocity, and substrate for 19 benthic invertebrate species. They applied criteria for *Nectophyche lahontonensis* (Banks) (Tricoptera) to PHABSIM models to predict a relationship between streamflow and habitat area. A flow-habitat curve was developed (Gore and Judy 1981, Figure 10) to identify instream flow needs for benthic invertebrates, demonstrating the feasibility of developing habitat-flow relationships for macroinvertebrates as a strategy to inform instream flow needs assessments. Their initial (1981) recommendation was to select indicator invertebrate species with the narrowest range of habitat preferences, and apply their habitat criteria in instream flow assessments. However, given the perceived difficulties in macroinvertebrate sampling, taxonomic identification, and habitat suitability curve development, subsequent research has generally abandoned the use of species-specific habitat suitability curves (Orth and Maughan 1983, Gore et al. 2001, Jowett 2003). Instead generic curves for groups of taxa such as the "EPT fauna" [Ephemeroptera, Plecoptera, Trichoptera] are used. Orth and Maughan (1983) investigated habitat preferences for 20 species of benthic invertebrates in small woodland streams. They found that weighted means for depths ranged from 0.4 to 1.3 ft which they considered significant because the depths sampled ranged from 0.2 to 2.0 ft. Weighted means for velocity ranged from 0.4 to 2.6 ft/s, although only 5 of 20 species sampled had weighted means for velocity below 1.0 ft/s [footnote: means of depth, velocity, and substrate type were weighted by benthic community characteristics and biomass of selected taxa]. Their conclusion, based on fitted polynomial regressions, was that "optimum conditions for diversity" and biomass occurred at depths of 1.1 ft, velocities of 2.0 ft/s, and cobble/boulder substrates. Gore et al. (2001) provide generic curves for "Macroinvertebrate Community Diversity" which identified water depth, velocity, and substrate criteria that maximize the BMI species diversity. Their generic BMI habitat criteria, based on a pool of 2,500 samples (see Gore et al. 2001, figures 4-6) and that correspond with suitabilities of 0.5 and above (i.e., which we consider "good" BMI habitat) were: water depths of 0.4 to 1.1 ft, velocities of 0.9 to 2.7 ft/s, and substrate including sand, gravel, cobble, and boulders. Jowett (2003) reported that in small streams in New Zealand, benthic macroinvertebrates were generally most abundant at depths of 1.0 to 1.6 ft and velocities of 1.6 to 3.2 ft/s. Jowett (2003) also noted that the relative abundance of invertebrates usually decreased as depth increased.

The Mono Basin Stream Scientists did not include aquatic macroinvertebrate targets in the Termination Criteria and did not monitor macroinvertebrates as part of the stream monitoring program. However, quantifying BMI habitat rather than directly measuring productivity provides an effective (and less expensive) mechanism for identifying instream flows. Our primary assumption is that abundant, hydraulically complex riffle habitat, along with suitable water temperatures, will promote high BMI productivity. Our BMI habitat study sought to determine if the area of BMI habitat varied over a range of baseflows suitable for adult trout foraging. Assuring that instream flow recommendations for trout habitat also provide productive riffle habitat (i.e., the combination of suitable hydraulic and temperature conditions) for BMI production is a key factor in maintaining ecosystem processes in Rush and Lee Vining creeks.

2 METHODS AND MATERIALS

For both Rush and Lee Vining creeks, the Stream Scientists used criteria-based habitat mapping of specific trout and BMI micro-habitats at various test flows to generate habitat-flow relationships. This methodology is a relatively new alternative to the more traditional PHABSIM habitat modeling approach that was used in the original flow studies on Rush and Lee Vining creeks (CDFG 1991; CDFG 1993). Criteria-based habitat mapping at varying flows has been termed empirical habitat mapping (EHM), expert habitat mapping (EHM), demonstration flow assessment (DFA), and habitat criteria mapping (HCM).

Recent approaches to habitat mapping have emphasized repeatability (Stillwater 2006 and 2007; USFWS/Chamberlain et al. 2007; McBain and Trush 2009). Each method of mapping habitat polygons cited above used binary hydraulic criteria (depth and velocity) and habitat qualifiers (substrate composition cover types and distance to cover) to identify patches of good habitat for the salmonid species and life stages of interest, measuring the dimensions of the habitat patch, transferring these dimensions onto laminated ortho-rectified aerial photos or surveying the polygons directly to the photos on a laptop computer while in the field. The habitat polygons are then digitized using AutoCAD or ARC-GIS software to calculate the area of each polygon. Then total habitat area is calculated for each mapped test-flow to produce a composite habitat-flow relationship curve or habitat rating curve. A multitude of curves can also be generated for examining habitat area variations within specific stream reaches or within a single habitat unit over the range of test flows.

Past habitat mapping efforts have been criticized for lacking reproducibility because some methods included biologists' professional judgment in identifying habitat polygon boundaries, instead of relying solely on measured criteria (Railsback and Kadvany 2008; Gard 2009). To improve the reproducibility of habitat mapping methods, the Fisheries Stream Scientists developed brown trout habitat criteria based on measureable criteria (obtained from the scientific literature and from our previous field studies) and implemented a field protocol in which all points that defined a polygon boundary were measured and the distances between all points were also measured.

2.1 Rush Creek – Adult Brown Trout Habitat Criteria

Utilizing information from our literature review as well as detailed measurements of several habitat variables taken during our Rush Creek brown trout movement study, we developed a set of criteria that, when present together, describe preferred winter holding habitat for adult brown trout on Rush Creek. The holding habitats defined by these criteria are particularly important for adult brown trout in the winter, but are also important year-round for adult brown trout and for all sizes of brown trout during the winter. These specific criteria are: (1) water column depth $\geq$1.0 ft; (2) water column velocities within six inches of the stream bottom of $\leq$0.7 ft/s; and (3) the immediate presence of cover to hide an adult (250-450 mm) brown trout from surface detection (Table 1). Types of cover utilized by adult brown trout on Rush Creek during the movement study included undercut banks, woody accumulations, root wads, bubble curtains (water surface agitation), submerged vegetation (primarily Elodea), overhanging vegetation within 1.0 ft of the water surface), large boulders and/or water depth >3.0 feet that provided a place for an adult (250 to 450 mm) brown trout to hide from surface detection. These cover types were also used during the IFS. Preferred foraging habitats for adult brown trout were defined by the same depth and velocity criteria as winter holding habitat, but no association with cover was considered (Table 1).

Several habitat mapping studies have established a minimum polygon size for good habitat. McBain and Trush (2004) used a minimum polygon size of 20 ft^2 (roughly 2 m^2) to map juvenile salmonid habitat in the Oak Grove Fork of the Clackamas River and Stillwater Sciences (2006) set minimum polygon sizes for adult resident cutthroat trout at 21 ft^2; however both of these studies were conducted on much larger channels than Rush Creek. During the Rush Creek Movement Study we located radio-tagged brown trout in winter months holding in discrete habitats as small as 2' x 3' (6ft^2); however these patches of habitat were considered too small to count as good habitat. For adult brown trout winter-holding and foraging habitat in Rush and Lee Vining creeks, we selected a minimum polygon size of 12 ft^2 (Table 1).

Table 1. Habitat criteria utilized for mapping suitable brown trout habitat in Rush Creek.

Guild Name	Minimum Polygon Size	Water Depths	Maximum Velocity	Immediate Cover Present
Adult winter holding	12.0 ft^2	≥1.0'	0.7 ft/s	Yes
Adult foraging	12.0 ft^2	≥1.0'	0.7 ft/s	Not necessary

2.2 Lee Vining Creek – Adult Trout Habitat Criteria

Although the scientific literature suggests that rainbow trout may utilize foraging habitats with higher velocities than brown trout, the focus of the Lee Vining Creek habitat assessment was winter holding habitat, which we thought was more limited than foraging habitat. Thus, we concentrated most of our field mapping measurements on winter holding habitat and used the same criteria developed for Rush Creek for both brown and rainbow trout in Lee Vining Creek. We also have doubts that rainbow trout would naturally sustain their current composition of the Lee Vining Creek trout population if the annual and frequent stocking of catchable rainbow trout by CDFG at the diversion pond ceased. Thus, brown trout were considered the focal species during the Lee Vining Creek IFS.

Foraging habitat within Lee Vining Creek pocket pools was determined by the following criteria:

1. Depth – to qualify as a measureable polygon, a pocket pool had to have at least one point ≥1.0 ft and depths along the perimeter of the polygon had to be at least 0.5 ft.

2. Velocity – the maximum velocity for defining a pocket pool polygon was 1.5 ft/s. Pocket pool velocity boundaries were typically defined by shear zones around exposed boulders.

3. Minimum size – of a pocket pool polygon was defined as 9.0' ft^2.

2.3 BMI Habitat Mapping Criteria

Following more recent practitioners' development and use of generic habitat suitability criteria for BMI habitat, we developed a simplified set of habitat criteria for mapping BMI habitat in Rush and Lee Vining creeks. The criteria were selected based on our own independent Master's thesis research (Trush 1979, Mierau 1996) and the most recent literature that provided ranges in hydraulic variables and substrate types for generic BMI communities. These sources, described in Section 1.5 above, included Orth and Maugham (1983), Gore et al. 2001, and Jowett 2003) summarized in Table 2.

Table 2. Benthic macroinvertebrate habitat criteria from selected literature sources and criteria used in Rush Creek and Lee Vining Creek BMI habitat mapping.

Habitat Criteria	Orth and Maughan 1983	Gore et al. 2001	Jowett 2003	This Study
Depth (ft)	0.4 to 1.3	0.4 to 1.1	1.0 to 1.6	~0.2-0.4 to 1.5
Velocity (ft/s)	0.4 to 2.6	0.9 to 2.7	1.6 to 3.2	>1.5
Substrate (mm)	rubble (cobble) and boulder	sand, gravel, cobble, boulder	50 to 100	60 to 150

BMI habitat criteria were defined as follows:

- Depth: the minimum depth inundating the D_{84} particle size, up to a maximum depth of 1.5 ft. We selected a minimum depth based on the D84 particle size because it provided a means of scaling the depth criterion to individual riffles and to different mapping reaches. For example, riffles in Upper Rush Creek have D_{84} particle sizes ranging from 154 to 162 mm, whereas riffles in Lower Rush Creek have D_{84} particle sizes ranging from 75 to 161 mm. Lee Vining Creek riffles generally have much coarser substrate than Rush Creek. An upper boundary for depth based on two times the D_{84} diameter was initially considered, but a static depth of 1.5 ft was chosen instead to simplify field measurement and thus increase the reach lengths mapped.

- Velocity: greater than 1.5 ft/s. A lower boundary for velocity of 1.0 ft/s was initially considered, but a more conservative value of 1.5 ft/s was selected to render habitat areas and habitat-flow curves more responsive to the small changes in test flows magnitudes.

- Substrate: the D_{50} to D_{84} substrate size range, including medium-sized gravel approximately 0.2 ft in 'b-axis' diameter (6 cm or 2.5 inches), up to large cobble 0.8 ft in 'b-axis' diameter (25 cm or 9.85 in) in Rush Creek, and boulder substrate up to 1.2 ft in 'b-axis' diameter (36 cm or 15 in) in Lee Vining Creek;

- Temperature: initially a 'highly productive temperature range' of 45 ^{o}F (10 ^{o}C) as the daily minimum to 62 ^{o}F (17.2 ^{o}C) as the daily maximum was selected based on Hynes (1970); additional literature confirmation on this criterion (if available) will be provided for the Synthesis Report.

2.4 Rush Creek - Reach Selection

When CDFG conducted the initial instream flow study in Rush Creek, the approximately nine miles of channel between the upper end of the MGORD and Mono Lake was divided into six distinct reaches (CDFG 1991). Reach delineation was based primarily on channel gradient, channel confinement, tributary influences, riparian vegetation and surrounding topography (Table 3).

Table 3. Lengths and gradients of CDFG's study reaches of lower Rush Creek, Mono County, California.

Reach #	Reach Length (ft)	Elevation Loss (ft)	Gradient (%)
1	7,497	19	0.25
2	4,699	149	3.18
3	16,738	310	1.85
4	264	8	2.86
5	9,398	131	1.39
6	8,606	42	0.49
TOTAL	47,202	659	1.40

The Fisheries Scientists conducted two Class 4 and 5 pool surveys in 2002 and 2008. The 2008 survey updated the identification and enumeration of high-quality pools from the downstream end of the MGORD to the Mono Lake delta. The primary reason for conducting the second pool survey was to determine if the large SRF releases of 2005 and 2006 resulted in the formation of more high-quality pool habitats. Preliminary results of the 2008 pool survey confirmed that the bottomlands section, (from the Narrows downstream to the County ford including the 10-Channel), experienced continued development and improvement of pool habitats. These survey results emphasize that lower Rush Creek is a dynamic system where pool habitats are continuing to develop and improve as high flows interacting with the riparian vegetation continue to re-shape the system. The dynamic nature of this lower reach of Rush Creek must be kept in mind when considering flow-habitat relationships, as habitats can be expected to evolve and improve over time. The lengths of all individual riffle, flat-water, pool habitat units were measured following the pool classification system developed by Platts et al. (1983). Documenting the spatial distribution of habitat units throughout the stream assisted in the selection of reaches for the Rush Creek IFS that represented available habitats. Selection of habitat mapping reaches was weighted towards portions of the long-term electrofishing sections and where concentrations of our movement study fish over-wintered or spawned to ensure that previously obtained fish data can be used to recommend instream flows in the upcoming Synthesis Report.

Relying on the CDFG study, the 2002 and 2008 pool surveys, and our ten years of field experience, we identified two reaches of particular interest for habitat quantification. Reach 5, as defined by CDFG (1991) covers the "bottomlands" section of Rush Creek from the lower end of the Narrows downstream to the County Road ford crossing. Although we expect physical habitat conditions will continue to improve, this low-gradient section of Rush Creek currently contains clusters of high-quality pools with habitat for larger brown trout, as well as representative BMI riffle habitats. For example, within Reach 5, the sub-reach between the Ford and the Lower Rush monitoring section (including the 10-channel) contains several Class 5 pools with deep, complex habitat. These pools were also utilized by three large, radio-tagged brown trout during the Movement Study.

The second reach of interest encompassed the upper portion of CDFG's Reach 3 (sheep herder's cabin downstream through our Upper Rush monitoring section). Our rationale for selecting this portion of Rush Creek was based on the Movement Study results which indicated this section was seasonally utilized for fall spawning and winter holding by large brown trout that migrated out of the MGORD. When winter baseflow recommendations are made in the Synthesis Report to maximize preferred adult brown trout holding habitat in the bottomlands, the effect of these flows on habitat currently used by large brown trout in Reach 3 should also be evaluated.

Based on the pool survey results and input from LADWP, CDFG, MLC, and CalTrout, the following five reaches were selected for habitat mapping in the Rush Creek IFS (Figure 1):

1. Upper Rush Creek – the annual sampling section, plus an additional 650 ft of channel upstream of the sample section's upper boundary (approximately 2,100 ft of channel). The additional length of channel captured two naturally-formed pools that were utilized for late-fall spawning and winter holding by large brown trout radio-tagged in the MGORD during the Movement Study.

2. Lower Rush Creek – the annual sampling section (approximately 1,300 ft of channel). This section was selected due to the continuous (2000-2007) eight-year data set of fish population information, as well as Movement Study data regarding winter habitat utilization.

3. 10-Channel – approximately 1,200 ft of the 10-channel was mapped because this channel and the Lower Rush sampling section split the flow coming down Rush Creek.

4. Bottomlands – from the M&T gauge site downstream to the Ford. Within this reach are numerous Class 4 and 5 pools, as well as deep runs/glides and riffle habitats. This entire reach was approximately 3,700 ft in length; however a sub-reach of 1,400 ft was selected for habitat mapping.

5. County Road – mid-section of the County Road annual sampling section (approximately 1,000 ft of channel). This section was selected due to the continuous (2000-2007) eight-year data set of fish population information, as well as Movement Study data regarding winter habitat utilization.

2.5 Rush Creek - Test Flows

Habitat mapping was conducted in the selected representative stream reaches during test flow releases of 15, 30, 45, 60 and 90 cfs. Each test flow was released for a two-day period. A test flow of 45 cfs was selected because this rate has been the most common baseflow released since Order 98-05 was executed; thus the majority of our fisheries field work including annual electrofishing, pool/habitat surveys and movement study were conducted at this stream discharge. The lowest test flow of 15 cfs was selected because it approximated the summer, fall, and winter median unimpaired baseflow for a “Dry” runoff year on Rush Creek (McBain and Trush 2004). The 30 cfs flow provided a mid-point for evaluating changes in habitat availability. Two successively higher test flows, 60 and 90 cfs, were also selected for evaluation. These higher test flows were used primarily to help calibrate the temperature model and to evaluate BMI habitat in riffles. However, these higher flows were also selected to better evaluate changes in adult brown trout habitat availability as velocities increased with increasing flows.

2.6 Lee Vining Creek – Reach Selection

In September of 2008, a pool/habitat typing survey was initiated on Lee Vining Creek to assist in reach selection and criteria development for the IFS. Approximately 2,600 ft of the main Lee Vining Creek channel was surveyed, starting at the upstream split of the A-4 channel, working in a downstream direction. Within this reach, high-gradient riffles were the dominant habitat type, both by occurrence and percent of channel length (Table 4).

Within these extensive reaches of high-gradient riffles we noted the frequent occurrence of pocket pools, low-velocity areas immediately downstream of boulders, and observed adult trout (both brown and rainbow) in many of these areas. In most cases, the area of a pocket pool was visually obvious by the shear-lines of higher velocity streamflow on either side of an exposed or slightly submerged boulder. Pocket-pool habitats with maximum depths ≥ 1.0 ft and low velocity areas of at least 12 ft^2 were counted during this pool survey (Table 4). Based on the initial habitat survey, pocket pool habitat within high-gradient riffles was considered an important component of summer forging habitat to map during the Lee Vining Creek IFS.

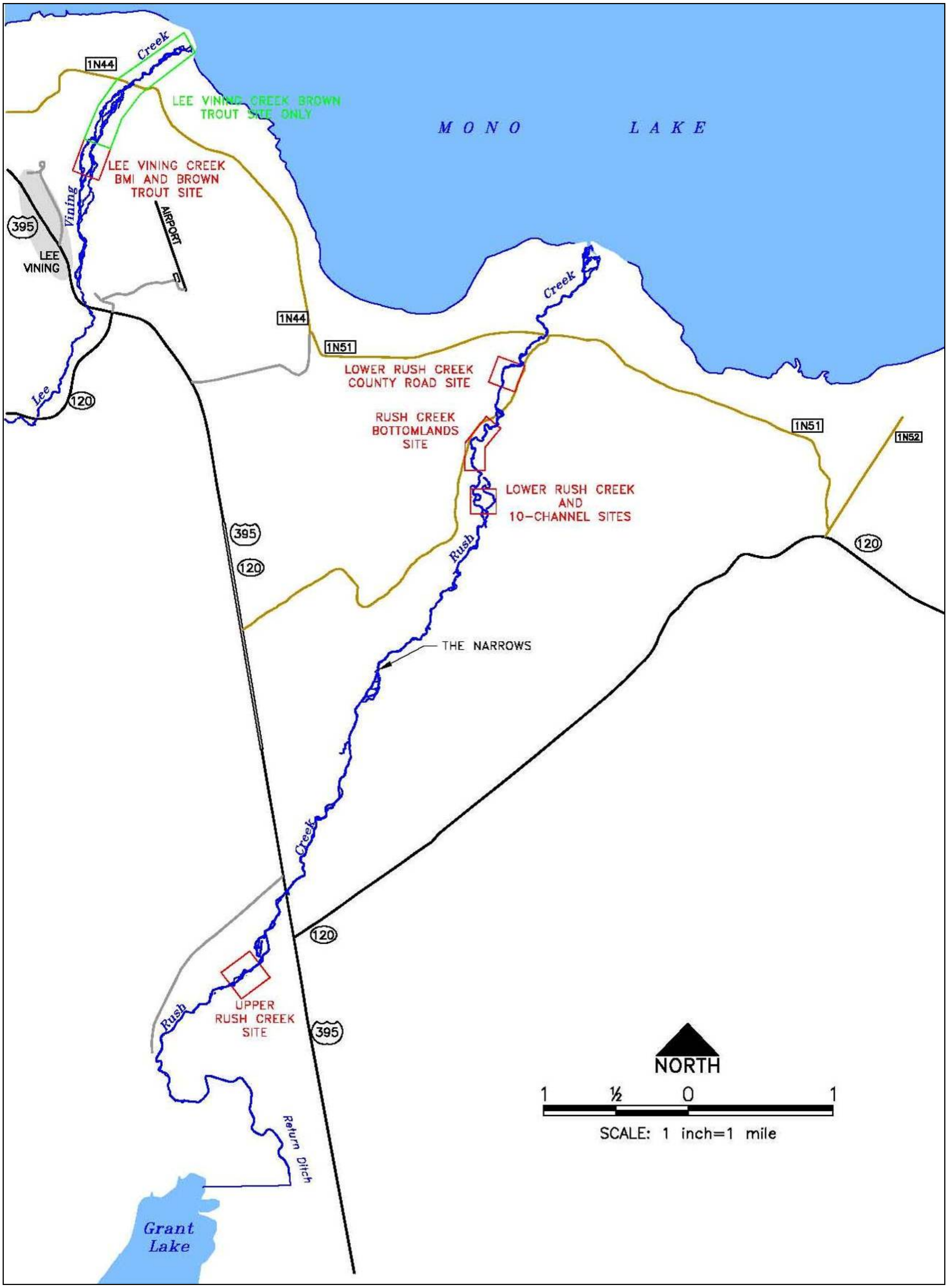


Figure 1. Location of mapping reaches for the Rush and Lee Vining creeks IFS, 2008 and 2009.

Table 4. Summary of habitat units identified and measured in Lee Vining Creek on September 13th and 19th, 2008.

Habitat Type	Number	Cumulative Length (ft)	Percent of Total Channel Length	Comments
High Gradient Riffle	12	2,027	79.4%	74 pocket pools
Glide/Run	8	309	12.1%	
Class 3 or less Pool	4	141	5.5%	
Class 5 Pool	1	76	3.0%	Extensive u/cut banks

The pool/habitat survey on Lee Vining Creek was continued in April of 2009 downstream to the Mono Lake delta and extended an additional 1,400 ft upstream from the A-4 channel split so that a total of 10,000 ft of channel was surveyed. Completion of this survey along nearly two miles of channel provided additional information on habitat types, documented the relative scarcity of pools and provided a baseline assessment to compare to future pool surveys (as was done in Rush Creek between the 2002 and 2008 surveys). The composition of habitat types changed in a downstream direction with run and pool units becoming more frequent as channel gradient and confinement decreased. In fact, the highest concentration of pools was identified downstream of the County Road on lower Lee Vining Creek (15 pools in 3,060 ft of channel compared to nine pools in 6,840 ft of channel upstream of the County Road).

Based on the pool/habitat survey results and input at the July 16, 2008 Mono Basin Restoration meeting in Bishop, the following reaches were selected for habitat mapping in the Lee Vining Creek IFS (Figure 1):

1. A contiguous 2,300 ft reach of channel, starting at the A-4 channel split. The upper portion of this reach contained extensive areas of high-gradient riffles and was selected primarily for pocket-pool and BMI habitat mapping. The lower portion of this reach was considered a transition zone out of the high-gradient reach where the occurrence of run and pool habitats increased. This lower reach contained several pools in which adult brown trout winter holding and foraging habitats were mapped.

2. Between the 2,300 ft contiguous reach and the County Road, several individual pools and runs were selected for mapping of adult brown trout winter holding and foraging habitats.

3. Downstream of the County Road, two contiguous reaches were selected for mapping of adult brown trout winter holding and foraging habitats only. The first reach was 617 ft in length and started approximately 250 ft downstream of the County Road. The second reach was 300 ft in length and included three Class 4 pools immediately upstream of the Mono Lake delta.

Based on reviews of draft study plans for the Lee Vining Creek IFS by stakeholder groups, other reaches of channel were considered for habitat mapping between LADWP's diversion and the A-4 channel split. The upper section of Lee Vining Creek from the diversion downstream to Highway 395 was split into two reaches by CDFG for their IFS (CDFG 1993). The reach below the diversion was approximately 0.75 miles long and was described as meandering with short riffles and long shallow pools, stable banks and at a lower gradient than any of the downstream reaches (CDFG 1993). According to CDFG, the lower gradient of this reach was responsible for "significantly more pool representation (>30%) and less riffle representation (<20%) than the lower four reaches" (CDFG 1993). We examined this section on April 27, 2009 and determined this reach could not serve as a control reach to compare to reaches in Lee Vining Creek below Highway 395 due to differences in channel slope and confinement. We were also concerned that the influence of hatchery trout planted in the pond at LADWP's diversion would render any long-term biological monitoring in this upper reach meaningless in determining if recommended flow changes were beneficial to a naturally self-sustaining fishery.

The Lee Vining Creek reach from Highway 120 down to 395 flows through a steep gorge similar to the gorge reach in Rush Creek. This Lee Vining reach is dominated by step-pools and short cascades with drops over boulders and bedrock. In 1990, CDFG's habitat delineation for their IFS determined this reach was comprised, by percent occurrence, of nearly 80% cascade habitats (CDFG 1993). Examination of this reach on April 27, 2009 suggests that little change has occurred within this steep reach of Lee Vining Creek.

The Lee Vining channel below Highway 395 was prioritized for habitat mapping because the long-term fish and geomorphic data were collected in this reach, the reach is located on LADWP property, and this reach has the greatest potential for future change/recovery as a result of the maturing riparian vegetation community and SRF flow releases. This lower reach is also probably less influenced by hatchery trout than the reach immediately downstream of LADWP's diversion. Our electrofishing data suggests that there was a difference in hatchery rainbow trout influence between the Upper annual sampling section (discontinued in 2008) and the Lower annual sampling section (Hunter et al. 2000 – 2009).

2.7 Lee Vining Creek - Test Flows

Habitat mapping occurred in the selected representative stream reaches during stream discharge test rates of 12, 20, 28, 37, and 54 cfs. Each test flow was released to allow for one day of mapping. The stream discharge rate of 37 cfs is the flow release currently prescribed in dry-year types from April through September and was considered the reference flow for the data analyses of the trout habitat polygons. The 37 cfs discharge was also quite similar to the currently prescribed winter baseflow during normal and wet year types. The next lowest discharge selected for habitat mapping was 28 cfs and was chosen because it is close to the currently prescribed winter baseflow of 25 cfs during dry-year types. The two lowest test flows of 12 and 20 cfs were selected to assist in evaluating changes in habitat availability between 12 and 28 cfs, the range where we suspected large amounts of winter holding habitat would occur. The highest test flow of 54 cfs was selected because it is the currently prescribed flow from April through September in normal and wet year types. However, we suspected that the highest test flow would provide minimal habitat that meets the adult trout criteria due to excessive velocities. For example, in September of 2005 we were barely able to wade and electrofish Lee Vining Creek at 50 cfs and in September of 2006 we were unable to sample at 60 cfs due to unsafe wading conditions.

2.8 Rush Creek – Field Methods

The selected reaches of Rush Creek were mapped by two, three-person teams. Habitat mapping occurred with a team usually working the reach in a downstream direction. The first team member used a Marsh-McBirney® flow meter with the sensor mounted 0.5' from the bottom of a six-foot long stadia rod marked in 1/10th foot increments to accurately delineate the velocity boundaries of a polygon. The team member using the velocity meter would locate the polygons and initiate the delineation of the polygon. Typically, a shear zone of velocity bounded the mid-channel side of a polygon and the inner (bank-side) boundary was often defined by the minimum depth criteria. The second team member used a carpenter's tape to locate the depth boundary on the bank-side directly opposite the velocity break identified by the first team member, including probing underneath undercut banks to determine the proper width of the polygon. Once the minimum depth boundary was located, the second team member would measure the width between the two points and verbalize this measurement to the third team member. This third team member was the designated drawer and their responsibility was to locate the start of the polygon on the aerial photograph and transcribe point locations and widths as called-out by other team members. Points were drawn on the laminated photos with fine-tipped indelible markers and widths between points were measured with a ruler to accurately translate the lengths and widths of the polygon measured by the other two team members. The 11" x 17" laminated aerial photos had a scale of 1" = 10 ft with a 0.5" (scale = 5 ft) grid layer superimposed on them.

Once an initial velocity-boundary point was located and the width of the polygon at this location was measured; the crew member with the carpenter's tape measured a five-foot distance straight downstream from the velocity point and the process was repeated with the determination of a new velocity boundary-point measured with the flow meter. A minimum of ten velocity/depth measurements were taken per polygon; however most polygons required additional measurements. When a foraging polygon was completed based on the velocity and depth criteria; the area of winter holding habitat within the foraging polygon was determined by measuring the extent of the polygon where cover was available. Typically, the team member with the carpenter's tape measured the extent of cover underneath woody accumulations and undercut banks while determining the minimum depth boundaries. In some cases where winter holding habitat consisted of woody accumulations or overhanging riparian vegetation that was visible on the aerial photographs, the drawer would delineate the winter habitat as the edge of these features. To differentiate between types of polygons, a blue marker was used to depict foraging habitat and red marker for winter holding habitat. Once a polygon was closed, all team members reviewed the dimensions transcribed onto the laminated photograph by the drawer to confirm that the polygon was accurately depicted.

Each mapping team consisted of two fisheries consultants and a LADWP field biologist from the Bishop Office. All velocity measurements and polygon delineation on the photos was done by the consultants. For consistency, team personnel were kept the same and each team mapped the same reaches at all five test flows. Prior to mapping habitat polygons the two teams worked together to standardize their methodology and mapping teams reviewed each day's mapping results with each other to ensure consistency in their mapping efforts.

2.9 Lee Vining Creek – Field Methods

On Lee Vining Creek, a three-person team mapped winter holding and foraging polygons within primary pools and runs in the two reaches downstream of the County Road Ford using methods consistent with the Rush Creek IFS. Polygons at a 1" = 10 ft scale were transcribed onto waterproof graph paper that had 10 squares per inch and the general location of each polygon was marked on laminated aerial photographs. The reasons for not drawing polygons on the aerial photos were two-fold: when blown-up to a useable scale, the photos had very poor resolution. Secondly, the photos were also taken in July of 2008 when the riparian vegetation was fully leafed-out. Both of these factors, blurred/pixilated quality and dense foliage made it quite difficult to accurately locate polygons on the photo and in many cases; the habitat location (or an entire pool unit) was completely obscured by riparian foliage. Because the primary study objective was to accurately map changes in habitat area across the five test flows, we decided to utilize graph paper.

A two-person team mapped pocket pool polygons in the 2,300 ft contiguous reach that started at the A-4 channel split. This team also mapped winter holding and foraging polygons within several primary pools and runs located upstream of the County Ford. One team member used the velocity meter mounted on the wading rod to locate pocket pool polygon velocity and depth boundaries; and used the carpenter's tape to measure polygon widths. The second team member transferred point locations and widths as called-out by first team member onto waterproof graph paper at a scale of 1" = 10 ft. The general location of each pocket pool polygon was marked on 11" x 17" laminated aerial photographs (scale: 1" = 25 ft). Due to the relatively small size and often complex shapes of the pocket pool polygons, distances between point measurements were typically less than the five feet; often as short as two to three feet.

2.10 BMI General Field Methods

Quantifying the relationship between BMI habitat and discharge in Rush and Lee Vining creeks required the following steps: (1) define 'BMI habitat' by identifying ranges in physical variables (binary hydraulic and substrate criteria) that provide suitable hydraulic and substrate conditions, (2) relate BMI area to streamflow by habitat mapping over a range of flows. In the Synthesis Report, we will compare water temperatures obtained from the Rush Creek SNTEMP model and from empirical water temperature data to water temperatures reported the scientific literature that encourage high invertebrate productivity.

Microhabitat mapping applied binary hydraulic criteria (depth and velocity) and substrate criteria in the field to delineate patches of BMI habitat within designated study reaches for a range of selected test flow. Discrete patches of riffle that met our criteria were mapped by one of two methods: for the Rush Creek IFS they were hand drawn onto laminated aerial photo basemaps and for the Lee Vining Creek IFS they were surveyed with GPS equipment (described below). Habitat polygons mapped onto aerial photo basemaps were digitized using AutoCAD computer software to calculate the area of each habitat patch. Despite there being some disadvantages to using GPS technology in habitat mapping (e.g., reliance on satellite coverage), mapping with a GPS achieves a high level of precision is also often faster than other methods. When combined with strict adherence to HSC and adequate depth and velocity measurements to define polygons, the reproducibility of the method is improved.

Once the BMI habitat patches were digitized and rectified in 2-dimensional (planform) space, the total area was summed for each streamflow to produce a composite habitat-flow curve showing the relationship between discharge and total habitat area. For each study reach, we plotted habitat-flow curves for individual segments of study reaches (e.g., alternate bar units or meander bends), and a composite curve plotting all the habitat area for an entire reach against discharge.

The X-axis in a habitat-flow curve is discharge. Microhabitat mapping thus required an accurate measure of stream discharge estimated contemporaneously with field mapping. In Rush Creek, several reaches were mapped, each with potentially different discharges as well as different proportions of the total discharge released below Grant Lake. But each reach had a consistent discharge for the entire length of the reach. Discharge was measured in the field for each reach on each mapping day, but the LADWP flow releases the MGORD (for Upper Rush Creek) and the MGORD+Parker+Walker (for Lower Rush Creek) were used in habitat-flow curves. Discharge measurement methods and results for Rush Creek are reported in the RY 2008 Annual Report (McBain and Trush 2009). In Lee Vining Creek, the presence of multiple side-channels and braided channel sections, and prevalence of coarse substrates reduced the utility of field discharge measurements, and discharge was not measured. For Lee Vining Creek, the LADWP flow release from the Lee Vining Intake was used for habitat-flow curve x-axis values.

Temperature requirements for BMI will be evaluated with the Rush Creek temperature model currently being developed by the Fisheries Scientists. The model will be used to predict water temperature conditions corresponding to trout habitat flow recommendations, then consider the effects of those predicted temperatures on benthic macroinvertebrate habitat area and productivity. The temperature analysis is not included in this report, but will be a component of the Synthesis Report.

Panoramic photographs were taken along each study reach at fixed photo points, during each test flow on Rush and Lee Vining creek. Rush Creek had 15 photo points; Lee Vining Creek had four photo points. These panoramic photographs are a useful tool in assessing flow conditions and to demonstrate changes in channel and habitat features as flows change. As a demonstration tool, habitat polygons will be transcribed onto a few selected oblique panoramic photos in the Synthesis Report to demonstrate spatial changes in BMI habitat area.

During the microhabitat mapping, several key features of the study reach were delineated in addition to the BMI polygons. The wetted edge of the channel was mapped in each reach at each flow (unless steep banks precluded a change in wetted edge of channel from one flow stage to the next). Water surface elevations were marked at our monitoring cross sections for later survey, to be used to develop stage-discharge rating curves in study reaches. The riffle crest thalweg (RCT) depth was estimated to the 0.1 ft and the location of the RCT was recorded on field maps or a GPS point was collected. The RCT is the deepest point (thalweg) along the hydraulic control at a pool-riffle transition, or the point that determines the upstream pool's water surface elevation at zero flow. The RCT depth can be used to evaluate fish passage feasibility at each test flow.

2.10.1 Rush Creek - BMI Mapping Methods

In Rush Creek, BMI habitat was mapped in August 2008, during a two-week test flow period. Hydraulic criteria were measured in the field using a transparent velocity headrod (Fonstad et al. 2005). BMI habitat patches that met our physical habitat criteria were mapped using laminated aerial photos as field base-maps. BMI habitat was mapped in the same five representative stream reaches mapped for brown trout habitat during flow releases from the MGORD that targeted 15, 30, 45, 60 and 90 cfs. Those reaches included Upper Rush Creek (1,403 ft), the Lower Rush Creek mainstem (1,279 ft) and 10-Channel (823 ft), the Rush Creek Bottomlands reach (between the 10-Falls and the wet ford crossing) (2,157 ft), and the County Road reach (between the wet ford and Test Station Road [County Road]) (1,421 ft) (Figure 1). Discharge was measured within each mapping reach the morning the reach was mapped with one exception: discharge measured at lower Rush Creek below the 10-Falls was applied to the County Road reach (Table 5). Once the field habitat mapping was complete, habitat polygons were digitized and areas were quantified for each mapped discharge. Because the reach lengths and consequent habitat area totals were slightly different, we standardized the reach-wide habitat area as habitat density, expressed as square-feet of habitat per 100 feet of channel.

Two additional channel features were also mapped: (1) the wetted edge of the stream in the mapping reaches to allow computation of riffle area (as a meso-habitat unit), and (2) riffle crest thalweg depths which are the threshold depths that potentially impede trout movement along stream reaches.

2.10.2 Lee Vining Creek - BMI Mapping Methods

BMI habitat was mapped on Lee Vining Creek during a one-week test flow period in April and May 2009. BMI habitat was mapped in 1,371 ft of the upper mainstem of Lee Vining Creek (Figure 1). Test flows were released from the Lee Vining Creek at Intake targeting 12, 20, 28, 38, and 54 cfs. Microhabitat mapping crews on Lee Vining Creek used digital velocity meters with graduated top setting wading rods to measure depth and velocity criteria, and habitat polygons were recorded in the field using a Trimble GeoXH GPS receiver and a digital rangefinder compass. The Trimble GeoXH GPS receiver with Zephyr Antennae is capable of producing sub-decimeter real-time positioning (high precision). Substrate criteria were visually estimated, and were generally suitable along the entire mainstem BMI mapping reach. Using the wading rods and digital flow meters, the field mappers measured water depths and velocities, located patches of riffle that met the hydraulic criteria, then walked the boundaries of each habitat patch by collecting numerous surveyed points with the GPS receiver and rangefinder compass. Surveyed points defining BMI habitat patch boundaries were immediately visible on the Tablet PC (using Terrasync Pro® software), with the aerial photo imagery in the background to confirm the point's position. The GPS point was then "attributed" as a BMI habitat patch boundary. Once the mapping fieldwork was completed, GPS points determining the habitat units were brought into GIS software to delineate habitat polygons, from which habitat area was then calculated.

2.11 Channel Widths

Although the Fisheries Scientists' primary focus during both IFS (Rush and Lee Vining creek) was to accurately measure changes to the surface area of winter holding and foraging habitats preferred by adult brown and rainbow trout; during all five test flows we also measured changes in the wetted widths of several representative riffle areas within our study reaches. Because riffles provide key habitat for fry and juvenile trout as well as for aquatic macroinvertebrates, we measured changes in the wetted widths of select riffles to act as a surrogate for evaluating potential changes to the habitat of non-adult trout and important food chain organisms. During both field efforts, pin-flags were set at various locations within riffles to mark the wetted width at the first test flow. At each successive test-flow the distance from each pin-flag to the new wetted edge was measured and recorded.

In addition to setting the pin flags, at each test-flow, personnel from M&T marked the wetted edge on both stream banks (left and right) with survey nails at established cross-sections. These nails were then surveyed to determine both changes in channel width and water-surface elevation at each test-flow.

2.12 Photo Points

During both studies, photo points were established for the purpose of visually documenting changes in flow patterns at each test flow. Digital cameras were used and photos were taken on the camera's "panoramic" setting so that photos could be stitched together to form a long, panoramic photograph. These composite photographs visually depict relatively long lengths of channel compared to an individual photograph.

Photo points were typically established within the IFS mapping reaches. However, during the Rush Creek IFS panoramic photo points were established in the gorge section downstream of the MGORD so that changes in channel form could be visually evaluated within this steep, confined channel reach.

2.13 Flow Measurements

During the Rush Creek IFS flow measurements were made at each test flow in at least one mapping reach to account for variations between target and actual releases at the MGORD, Parker and Walker accretions, and streamflow losses along the Rush Creek corridor. In preparation for the IFS, M&T personnel installed a Global WL-16 pressure transducer and datalogger on the lower Rush Creek mainstem below the 10-Falls (at XS-9+82) to record stage height. The datalogger was installed June 10th and removed October 21, 2008. During the Rush Creek IFS, M&T and DWP field crews collected at least one discharge measurement within or near each mapping reach during the five test flow releases.

In Lee Vining Creek, flow measurements were made during each test flow release by M&T personnel in the main channel just upstream of the long-term monitoring cross-section #XS 03 + 73 and in the A-4 channel near the confluence with the B-Connector channel.

2.14 Data Processing and Analysis

M&T personnel digitized the polygons using AutoCAD software. Each basemap was digitized on a tablet calibrated to real-world coordinates (California State Plane, NAD27, Zone 3, Feet). No boundary adjusting, smoothing, or aggregating was attempted. The next step was to build topology for each mapping flow, where individual polygons were linked to their respective attributes to allow analysis and comparisons to proceed. Habitat rating curves established a quantitative relationship between abundance (ft^2) of brown trout winter holding and foraging habitats (Y-axis) and the test flow (cfs) (X-axis), at the time habitat mapping was performed. Once all the habitat polygon data were compiled and discharges for the experimental flows computed and checked for error, the habitat rating curves were constructed. Because the Lee Vining Creek trout habitat polygons were delineated on graph paper, no attempt was made to calibrate these polygons to real-world coordinates.

The analysis of changes in habitat areas within the sets of polygons generated at each test flow was as straightforward as possible. For the polygons that depicted preferred adult brown trout habitats, we documented at what flows the total areas of winter holding and foraging habitats were maximized. Habitat-flow relationship curves were also generated to examine potential differences in habitat area between mapping reaches, as well as how habitat area fluctuated within individual pool units. We also examined potential differences between mapping reaches, as well as fluctuations within individual units. In Lee Vining Creek, the analysis of foraging habitats also examined the relative contributions between primary pools and pocket pools within riffle reaches.

A metric called “percent of maximum habitat” was derived for both holding and foraging habitats by dividing the surface area of each of these habitat types observed at each test flow by the largest total surface area observed for each of these types of habitats. Thus, the highest “percent of maximum habitat” was 100% when the maximum amount of habitat was observed and the amounts of habitat observed at all other flows were scaled to this maximum. Percent of maximum habitat values were computed for each type of habitat at each test flow for each mapped reach. Converting total areas to percentages allowed for more direct comparisons among the reaches by providing a standardized Y-axis. In addition, total surface area of each habitat type at each flow was standardized as the area of habitat per length of channel (“ft^2/100 ft”). This metric compared the densities of holding and foraging habitats among reaches and/or streams.

For brown trout fry and BMI habitat, we determined whether significant reductions occurred to the wetted widths of riffles at the lowest test flow compared to the higher flows, based on changes in the pin-flagged riffle widths. If the wetted widths at these riffles were significantly reduced, we would consider adjusting the recommended baseflows in the Synthesis Report to better meet these needs.

3 RESULTS

3.1 Rush Creek – Test Flow and Measured Releases

The order of test flow releases was: 45 cfs, 60 cfs, 90 cfs, 30 cfs, and 15 cfs. Each test flow was held to allow for two days of mapping and relatively rapid ramping occurred between test flows to maximize time for the mapping field effort. Flow measurements were made throughout the Rush Creek IFS by both DWP hydrographers and M&T personnel. DWP hydrographers measured flows at the downstream end of the MGORD. M&T crews measured discharge in Upper Rush Creek (~2,000 ft upstream of Old Highway 395), in Lower Rush (split channel), in the 10-Channel (split channel), and at the lower Rush Creek mainstem gauging site below the 10-Falls (full channel) (Table 5). The combined contributing flow from Parker and Walker creeks was 4.9 cfs as measured by DWP on August 12th and 20th, and was assumed to be stable during the 10 day IFS period. The 4.9 cfs release was assumed to emulate a probable wintertime flow contribution to Rush Creek (Table 5). The fifth column displays the MGORD actual measured release plus the Parker/Walker contributions (Table 5). As evident from the M&T measured flows within the mapping reaches downstream of the Narrows, flow was lost between the bottom of the MGORD and sites below the Narrows (Table 5).

We used the 15-minute flow data from the DWP MGORD gauge and from the Rush Creek XS-9+82 gauge (Figure 2) to verify that our instantaneous discharge measurements collected once during each test flow release represented the daily discharge at each study site (i.e., that the measured flow persisted during the habitat mapping). In Table 5, the MGORD Actual Release value is the average of the 15-minute discharge between 8AM and 4PM before flow changes

Table 5. Discharge values obtained from DWP and synoptic field measurements during the Rush Creek IFS habitat study, August 12-22, 2009.

					Measured Flow at Sites (cfs)			
Dates	MGORD Targeted Release (cfs)	MGORD Actual Release (cfs) #	Parker+Walker Contributution (cfs) *	Rush Creek Below the Narrows (cfs)	Upper Rush	Lower Rush	10-Channel	Ford - County Road
12-Aug	45	47.3	4.9	52.2				45.7
13-Aug	45	52.8 **	4.9	57.7	43.3	8.6	32.2	
14-Aug	60	60.9	4.9	65.8	64.0			57.6
15-Aug	60	60.6	4.9	65.5		12.1	48.1	
16-Aug	90	89.8	4.9	94.7	94.1	19.2	62.0	77.3
17-Aug	90	89.4	4.9	94.3				
19-Aug	30	33	4.9	37.9	33.5		22.6	27.1
20-Aug	30	32.9	4.9	37.8		6.1		28.8
21-Aug	15	17.1	4.9	22	17.9		12.3	14.1
22-Aug	15	16.9	4.9	21.8		3.0		

represents the average of 15-minute MGORD data between 8AM and 4PM

* represents combined flow measured by DWP at tributary confluences on 8/12 and assumed steady through habitat flow study

** flow release remained 46.9 cfs until mid-day, when flows were ramped up prematurely were made, which best represent MGORD flow releases present during the habitat mapping. The 15-minute data indicated the MGORD flows were stable during daylight hours when field crews were mapping habitat, and very close to the targeted flows recommended in the study plan (Figure 2). The only exception was the premature flow change on August 13th at approximately 11:30AM which was detected by mapping crews in Lower Rush Creek at approximately 4PM.

In summary, considering unavoidable flow losses along Rush Creek, minor diurnal fluctuations in lower Rush Creek, and the premature flow change made at the MGORD on August 13th , we concluded that the instantaneous discharge measurements collected at each habitat mapping site adequately represented flows present during each day of habitat mapping.

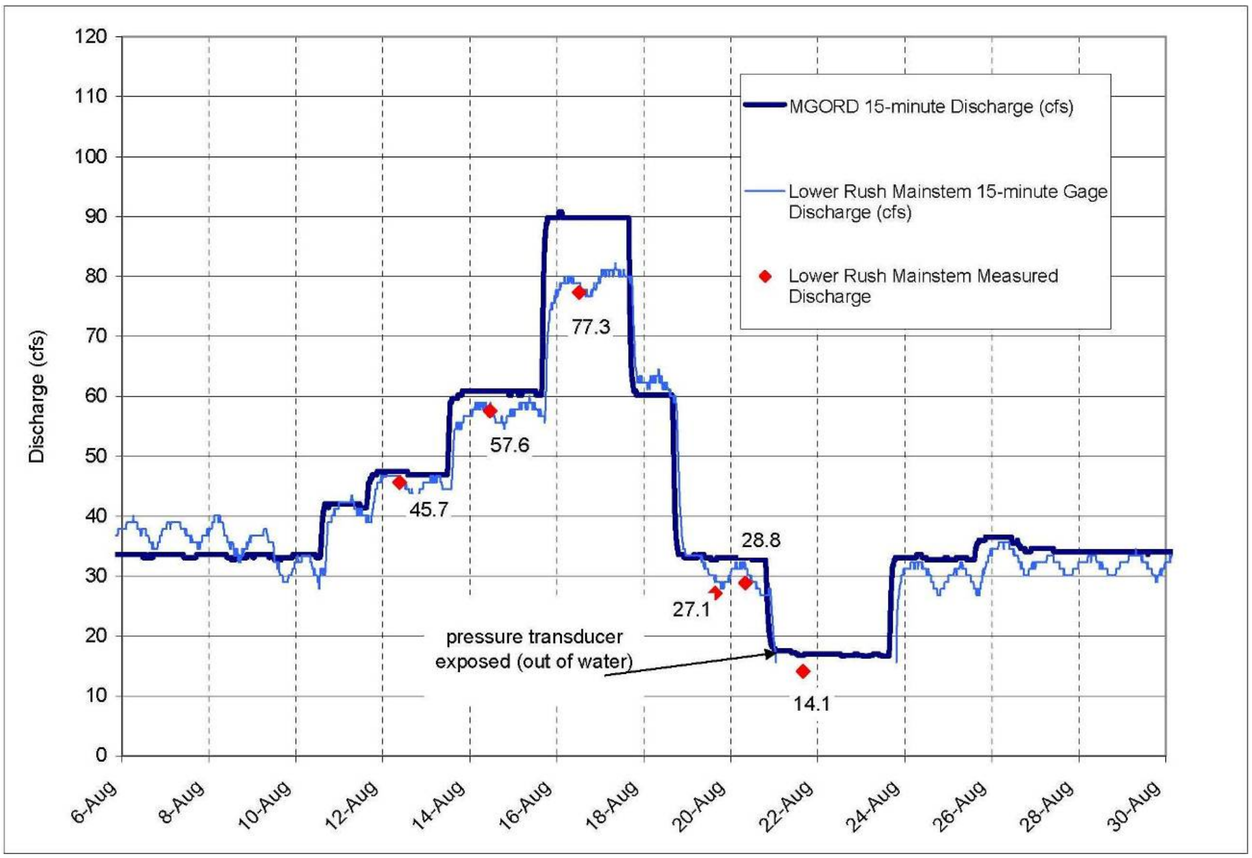


Figure 2. Plot of 15-minute discharge data for the DWP MGORD gauge and the M&T Lower Rush Creek gauge, with synoptic discharge measured during the August 2008 IFS.

3.2 Rush Creek – Overview of Field Mapping

The habitat mapping of the five selected reaches on Rush Creek occurred on August 12 – 22, 2008 (Figure 1). The actual lengths of the reaches mapped for adult brown trout habitat in Rush Creek were as follows: Upper Rush = 2,122 ft; Old Lower Rush = 1,344 ft; 10-Channel = 1,328 ft; Bottomlands = 1,432 ft; County Road = 776 ft. Based on the total main channel length of Rush Creek as measured downstream of the Narrows during the 2008 pool/habitat survey (25,336 ft), we mapped 4,880 ft of this length (or 19.3%) within our four IFS study reaches. This included mapping 18 out of 58 (or 31.0%) of the high-quality pools in Rush Creek downstream of the Narrows.

Habitat mapping at 45 cfs was a learning experience for both mapping teams, with the poor quality of the aerial photos presenting the greatest challenge. The blurred/pixilated quality and dense foliage made it quite difficult to locate one's self on the photo, let alone accurately locate the correct position of a polygon. Many of the Rush Creek aerial photos were also of poor quality due to glare caused either by the time of day the flight was conducted and/or the failure to use a polarizing filter. During the second day of mapping at 45 cfs both fisheries teams started writing all the measured polygon widths on the laminated aerial photos. This procedure was done for the remaining four test flows too (Figure 3).

After Rush Creek polygon data were entered into Excel spreadsheets and initial flow-habitat relationship curves were developed, we decided to drop the 45 cfs data set from the analyses due to the problems encountered with the aerial photos and adaption to these problems by field crews during the first 1.5 days of mapping. Fortunately, the 45 cfs test flow was a transitional point between larger amounts of habitat available at lower test flows and the steady decrease in habitat as test flows increased beyond 45 cfs (Figure 4).

3.3 Rush Creek – Winter Holding Habitat

The mapped reaches of Rush Creek contained significantly less winter holding habitat than foraging habitat, indicating that cover was not available within much of the habitat polygons with suitable depth and velocities (Figure 4). Total amounts of foraging habitat were considerably higher at all reaches and flows. The area of foraging habitat was highest (18,047 ft^2) at the lowest test flow of 12 cfs (Figure 4). The total amount of winter holding habitat was nearly equal at the two lowest targeted test flows, but increased slightly from 5,427 ft^2 at 15 cfs to 5,499 ft^2 at 30 cfs (Figure 4). Winter holding habitat for all five reaches was then plotted separately by reach to better display differences in holding habitat availability versus test flows (Figure 5). When analyzed separately by mapping reach, winter holding habitat responded differently to flow within the five different reaches (Figure 6), but foraging habitat responded similarly among the reaches (Figures 9 and 10). However, in general, both holding and foraging habitat areas were highest at the lower test flows. In some reaches the areas of these habitats were highest at the lowest test flow and in other reaches they were highest at the second lowest test flow. The only exception was for winter holding habitat in the Old Lower Mainstem mapping reach where winter holding habitat area was highest at the highest test flow; however, it

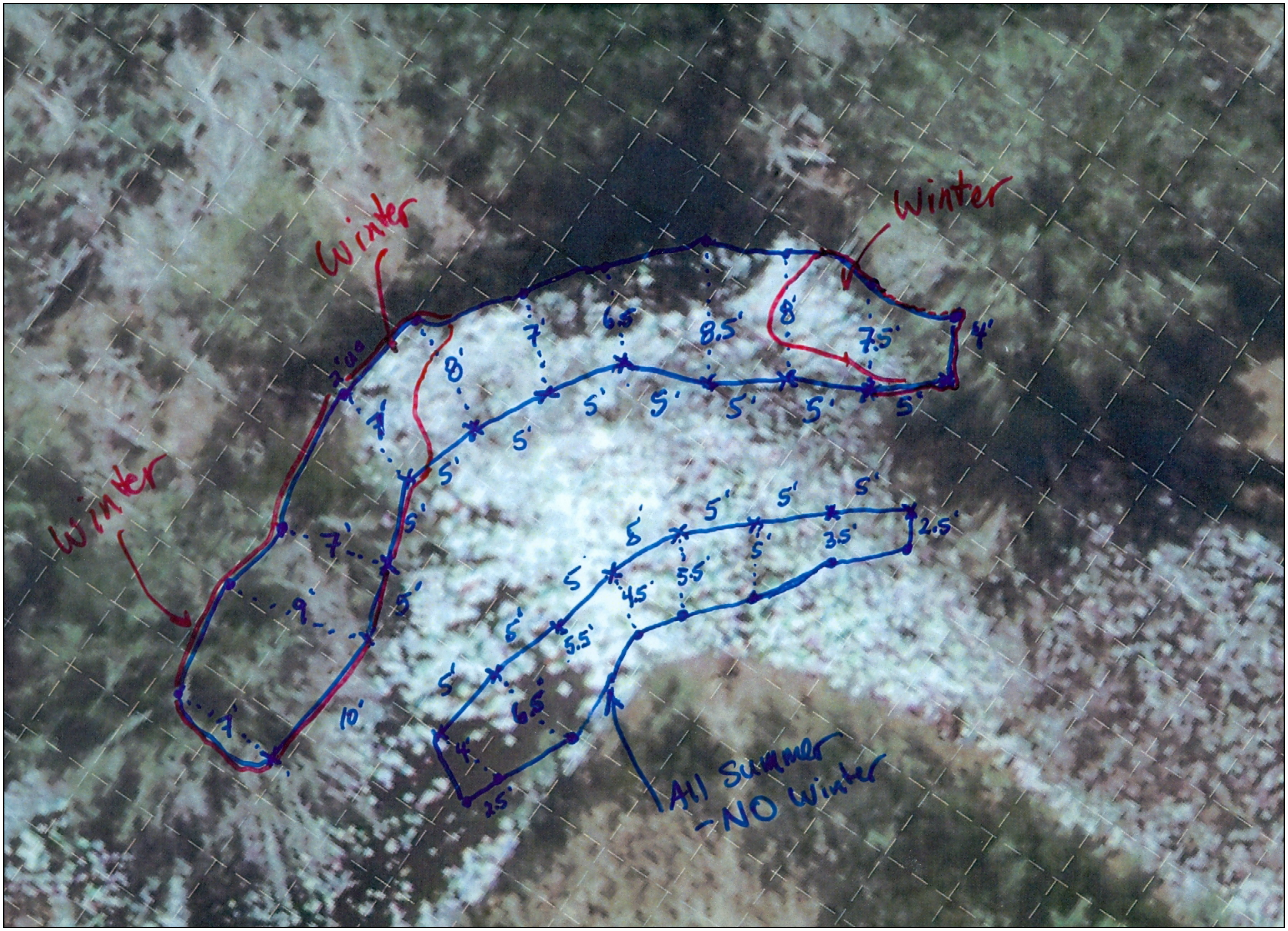


Figure 3. Habitat mapping example from the Rush Creek IFS on photo-sheet #13 from the Bottomlands reach at 30 cfs on August 20, 2008. Note the white areas that represent glare reflection off of the water's surface and make interpretation of the photo difficult.

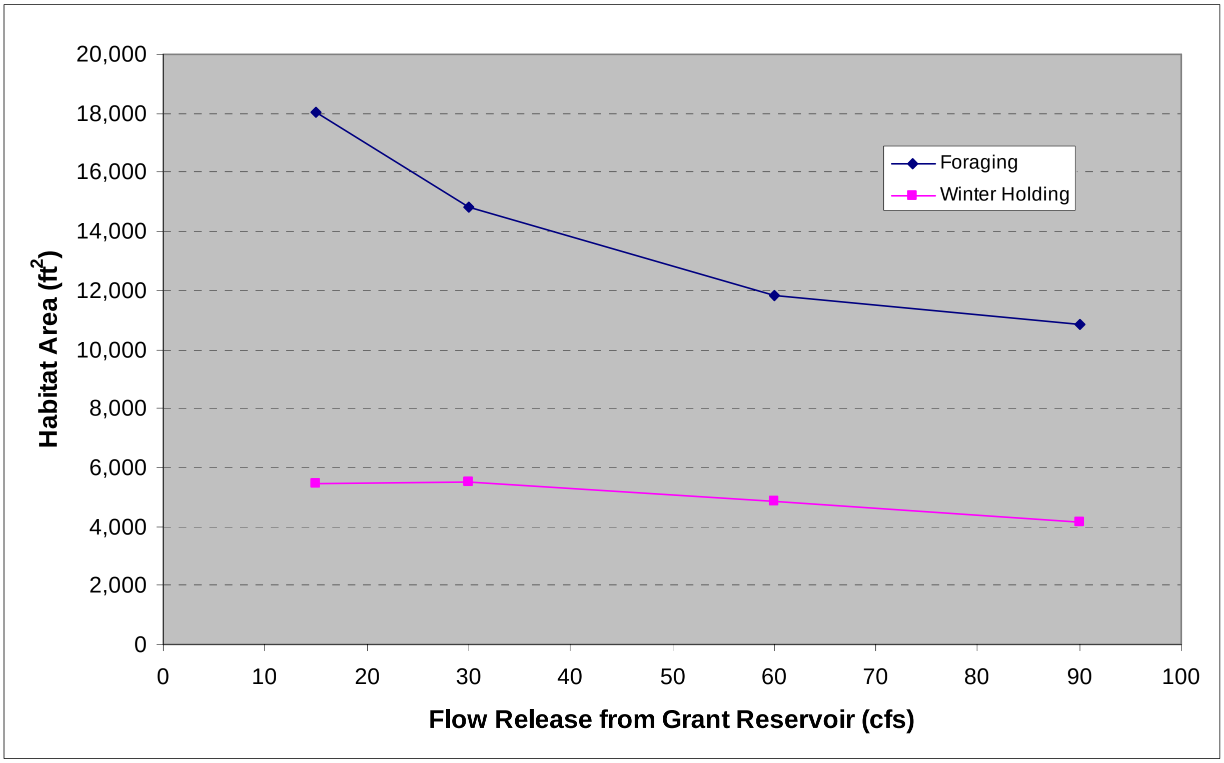


Figure 4. Adult brown trout winter holding and foraging habitat-flow relationship curves for Rush Creek, all mapping reaches combined.

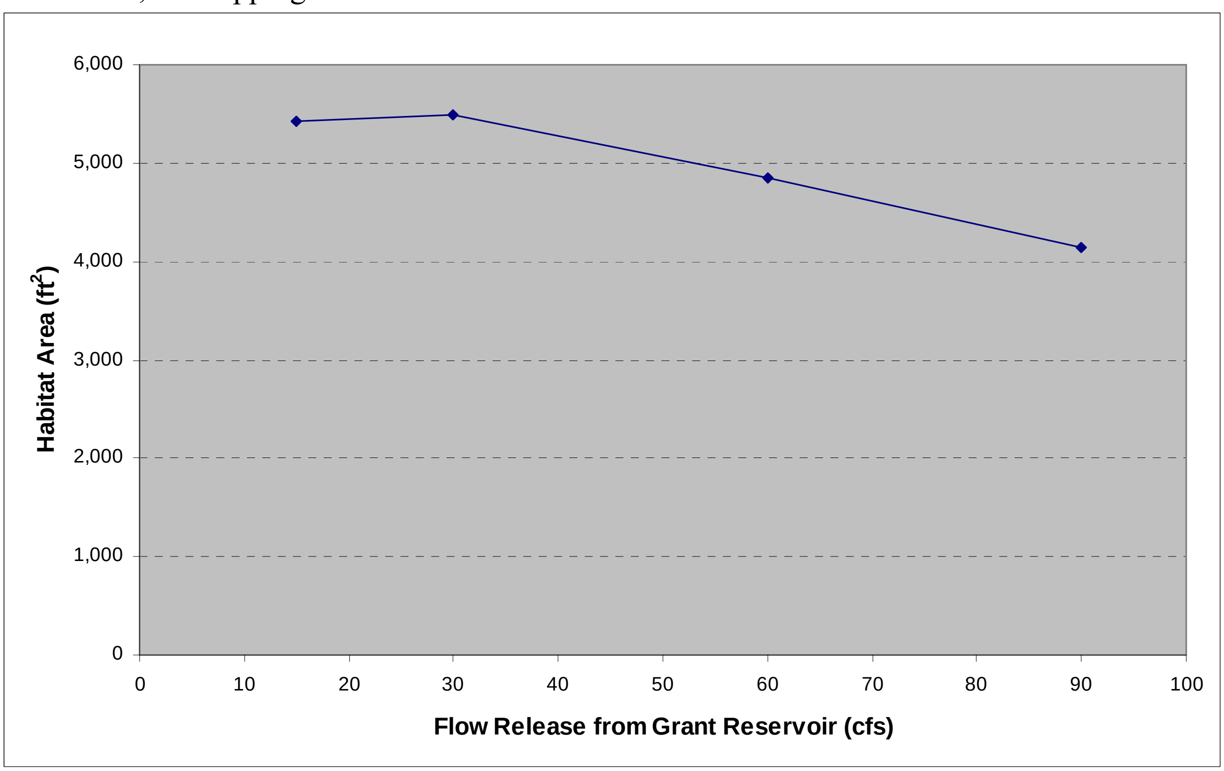


Figure 5. Adult brown trout winter holding habitat-flow relationship curve for all five Rush Creek IFS mapping reaches combined.

must be remembered that this reach was in a portion of Rush Creek with a split channel and the area of winter holding habitat within the other mapped channel (10-Channel reach) was highest at the second-lowest test flow. Since the Old Lower Mainstem mapping reach was comprised of a channel that had limited flow going down it at all but the higher test flows, winter holding habitat was more available at higher flows than at lower flows when very little flow went down this channel.

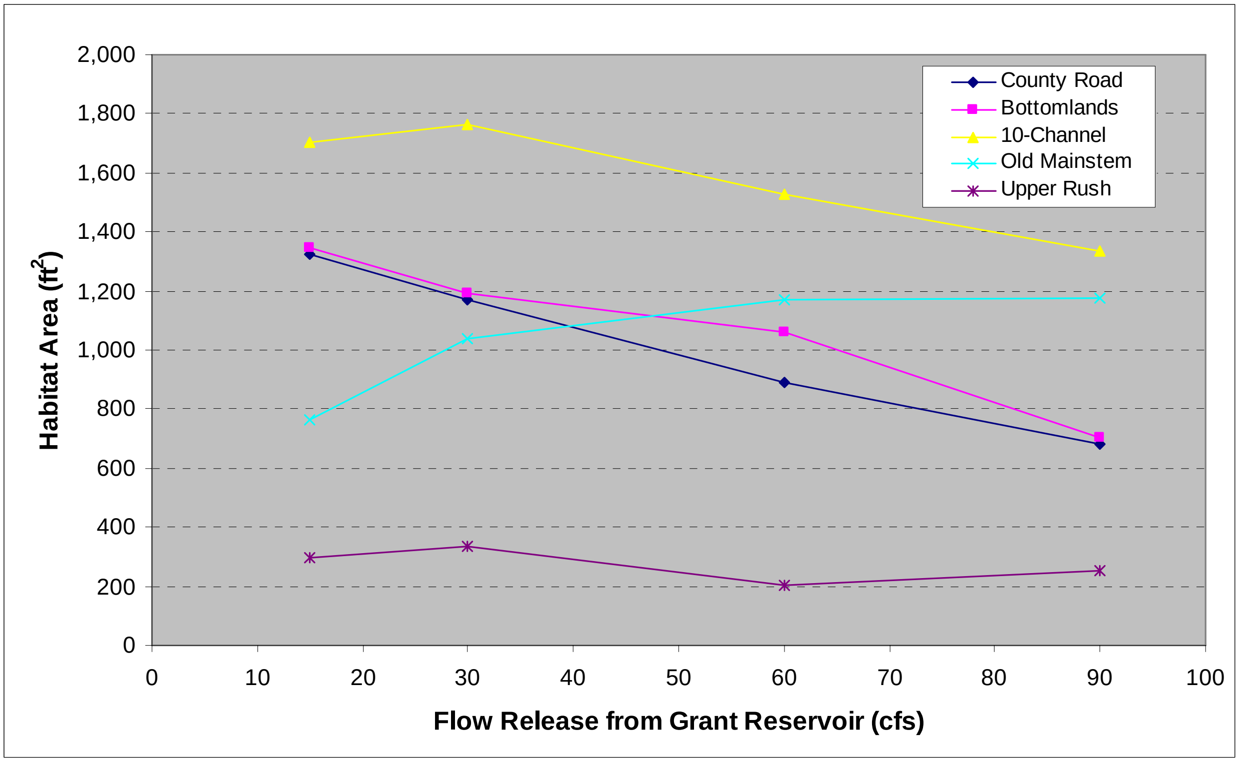


Figure 6. Adult brown trout winter holding habitat-flow relationship curves for each of the five Rush Creek IFS mapping reaches, August 2008.

Because a single flow release was split between the 10-Channel and the Old Lower Mainstem, a composite habitat-flow relationship curve was developed which combined the winter holding habitat areas of these two reaches (Figure 7). When combined, these two reaches accounted for a majority of the winter holding habitat within the five mapping reaches and this habitat was most available at the 30 cfs test flow release (Figure 7).

The total surface areas of winter holding habitat and foraging habitat at five study reaches on Rush Creek were summarized with the four test flow rates expressed as both MGORD Measured Releases and M&T Measured Flows (Table 6). "MGORD Measured Releases" were the daily mean flows at the MGORD, plus the 4.9 cfs combined accretion from Parker and Walker creeks. "M&T Measured Flows" were the discharge values measured by M&T near or within the IFS reaches at each test flow. As was previously presented, during all of the test flows, a portion of the released water was "lost" to the groundwater infiltration or side-channel flow before reaching the habitat mapping sites below the Narrows. For that reason, the measured flows were utilized when developing the habitat-flow relationship curves for adult brown trout downstream of the Narrows.

Changes to the percent of maximum winter holding habitat within each of the four reaches below the Narrows were plotted at each measured field flow (Figure 8). Mapping the Old Lower Rush and the 10-Channel reaches provided an opportunity to evaluate a wider range of flow/habitat relationships than was possible at the Bottomlands and County Road reaches, because these adjoining reaches shared the total streamflow that was present where they diverged.

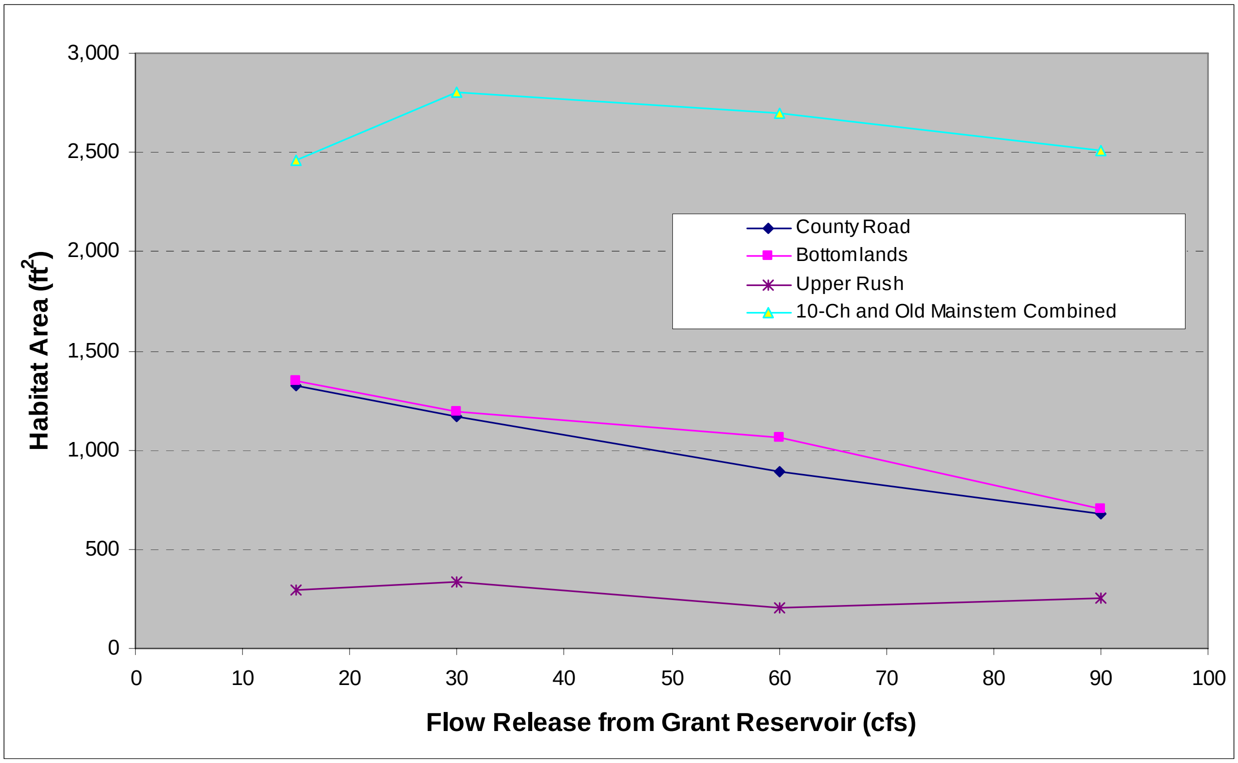


Figure 7. Adult brown trout winter holding habitat-flow relationship curves for Rush Creek IFS mapping reaches with the 10-Channel and Old Lower Mainstem combined, August 2008.

Prior to the high runoff years of 2005 and 2006, the Old Lower Mainstem Reach/electrofishing section was the "mainstem", conveying a majority of the streamflow. Since 2006, most of this shared flow has been directed down the 10-Channel (Table 6). Because the Old Lower Mainstem Reach was historically the main channel, this reach was an invaluable source of information for what could occur to adult brown trout holding habitat in Rush Creek below the Narrows at stream flows ranging from 3.0 to 19.2 cfs (Figure 8). Even though the riparian vegetation has started to encroach into this relic section of mainstem channel; during the 2008 IFS mapping the pool and run habitats still retained their dimensions, depths, and cover elements from when this channel conveyed a majority of the streamflow. Winter holding habitat within the Old Lower Mainstem Reach declined at all of the flows less than 19.2 cfs, and especially when these flows were less than 12.1 cfs (Figure 8).

At the 10-Channel, the maximum amount of adult trout holding habitat was present at a measured flow of 22.6 cfs, with less of this habitat being present at both lower and higher test flows (Figure 8). At 12.3 cfs, 96.6% of the maximum amount of holding habitat was present. At 48.1 and 62.0 cfs, this amount was reduced to 86.5% and 75.6%, respectively.

At the Bottomlands and County Road reaches, the amount of winter holding habitat steadily declined as streamflows increased above 14.1 cfs (Table 6 and Figure 8). At 28.8 cfs, this habitat was reduced to about 88.5% of maximum at both the Bottomlands and County Road reaches. At the highest measured test flow that was evaluated (77.3 cfs), the amount of maximum winter holding habitat was reduced to 52.4% of maximum at the Bottomlands and to 51.5% at the County Road reach.

The habitat-flow relationship curves for the four study reaches below the Narrows can also be used to extrapolate or predict the percentage of maximum winter holding habitat that would be present at any measured streamflow up to 77.3 cfs (Figure 8). For example, if a measured flow of 15 cfs were present in the study reaches, roughly 98 to 99.5% of the maximum amount of habitat would be present. At 30 cfs, these percentages would range from 87 to 96%; at 60 cfs from 66 to 78%, and only about 53 to 56% at 75 cfs (see the vertical lines denoting these flows on Figure 8).

Table 6. Total surface areas of winter holding and foraging habitats mapped at five reaches during four test flows on Rush Creek during August 2008. Percentages of the "maximum" habitat area and standardized area per stream length (ft^2/100 ft) within each mapping reach at each test flow were also provided.

REACH NAME AND LENGTH	Test Flow Rate (cfs)		Winter Holding Habitat			Foraging Habitat		
	MGORD Measured Releases*	M&T Measured Flows	Area (ft^2)	Percent of Maximum Area	ft^2/100 ft	Area (ft^2)	Percent of Maximum Area	ft^2/100 ft
Upper Rush – 2,122 ft	17.0	17.9	294.7	88.1	13.9	1726.2	100	81.3
	33.0	33.5	334.5	100	15.8	1337.8	77.5	63.0
	60.8	64.0	205.7	61.5	9.7	731.6	42.4	34.5
	89.6	94.1	251.6	75.2	11.6	798.3	46.2	37.6
Old Lower Mainstem – 1,344 ft	21.9	3.0	761.4	64.5	56.7	3771.5	94.2	280.6
	37.9	6.1	1037.8	88.2	77.2	4002.9	100.0	297.8
	65.7	12.1	1171.2	99.5	87.1	3282.2	82.0	244.2
	94.5	19.2	1177.2	100	87.6	3136.6	78.4	233.4
10-Channel 1,328 ft	21.9	12.3	1702.6	96.6	128.2	4585.4	100	345.3
	37.9	22.6	1763.4	100	132.8	3555.0	77.5	267.7
	65.7	48.1	1525.3	86.5	114.9	2595.0	56.6	195.4
	94.5	62.0	1333.8	75.6	100.4	2471.0	53.9	186.1
Bottom-lands 1,432 ft	21.9	14.1	1346.8	100	94.1	4076.6	100	284.7
	37.9	28.8	1191.7	88.5	83.2	2940.2	72.1	205.3
	65.7	57.6	1060.8	78.8	74.1	2527.0	62.0	176.5
	94.5	77.3	705.9	52.4	49.3	1905.2	46.7	133.0
County Road – 776 ft	21.9	14.1	1321.5	100	170.3	3887.1	100	500.9
	37.9	28.8	1168.3	88.4	150.6	2971.7	76.5	383.0
	65.7	57.6	891.7	67.5	114.9	2683.9	69.0	346.9
	94.5	77.3	680.9	51.5	87.7	2531.7	65.1	326.3

*For the four mapping reaches downstream of the Narrows, this value includes the 4.9 cfs accretion from Parker and Walker creeks.

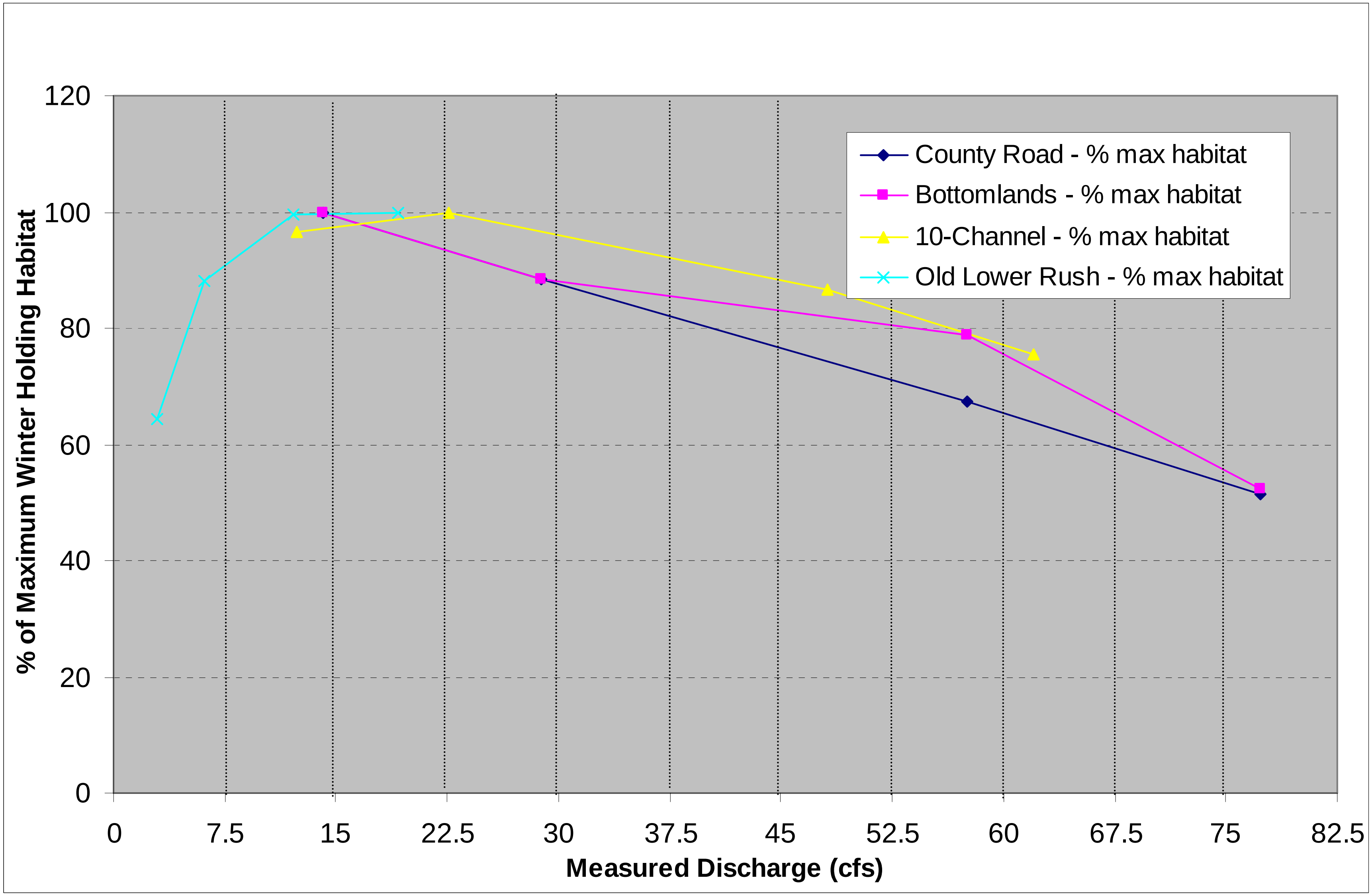


Figure 8. Percent of maximum winter holding habitat (ft^2) versus measured discharge (cfs) for the four Rush Creek mapping reaches located downstream of the Narrows, August 2008.

3.4 Rush Creek – Foraging Habitat

Foraging habitat was present in Rush Creek at all test flows and was comprised of polygons of at least 12.0 ft^2 located in primary pool and run/glide habitat units (Figure 9). When all five mapping reaches were combined, the amount of available summer foraging habitat was greatest (18,047.0 ft^2) at the lowest test flow of 12 cfs and decreased as flow increased (Figure 4). For all five mapping reaches combined, at the 54 cfs test flow the amount of available summer foraging habitat was 10,842.7 ft^2, approximately 60% of the maximum amount (Figure 4).

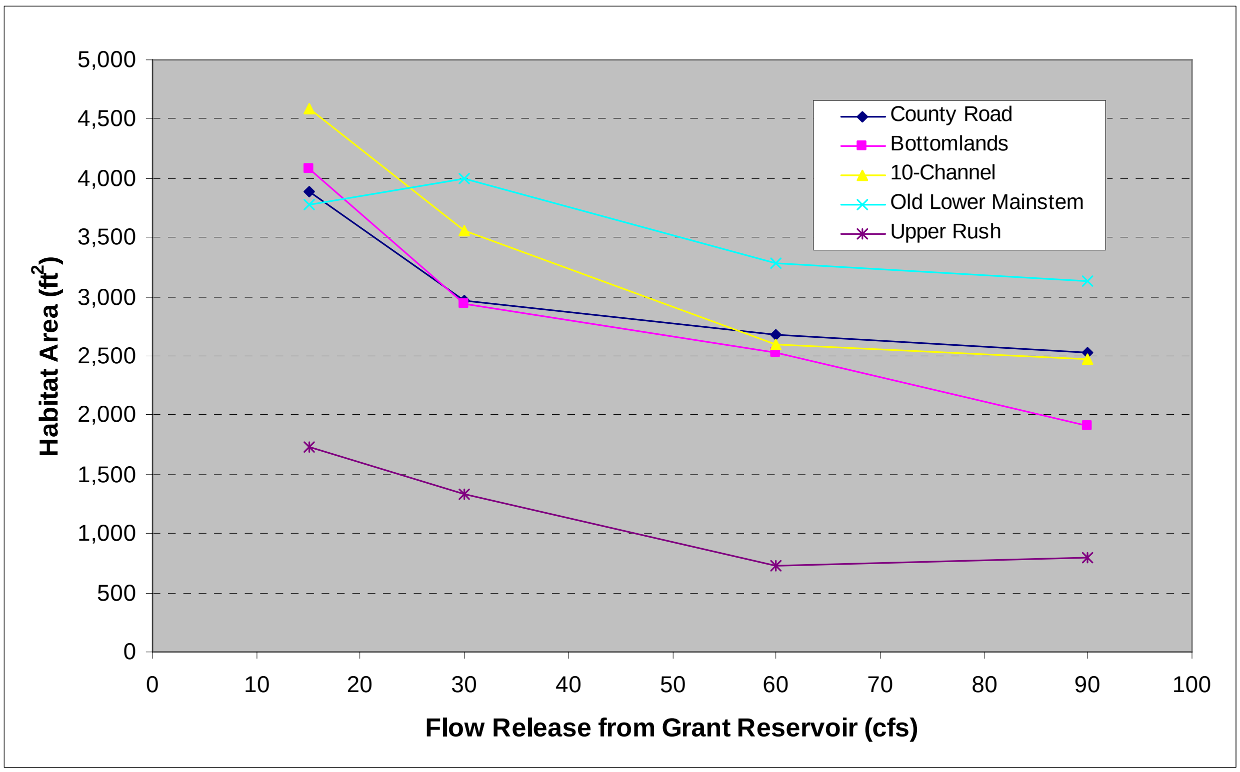


Figure 9. Adult brown trout foraging habitat-flow relationship curves for each of the five Rush Creek mapping reaches, August 2008.

Similar to the analysis of winter holding habitat, the percent of maximum foraging habitat was plotted against the actual measured discharges (Figure 10). The Old Lower Rush Mainstem mapping site was dropped from this analysis because the measured discharges in this split-channel reach (3.0-19.2 cfs) were lower than the expected range of summer baseflows to be recommended in the Synthesis Report. In the three mapping reaches displayed, foraging habitat dropped with each increase in measured discharge, with the largest drop occurring between the two lowest flows (Figure 10).

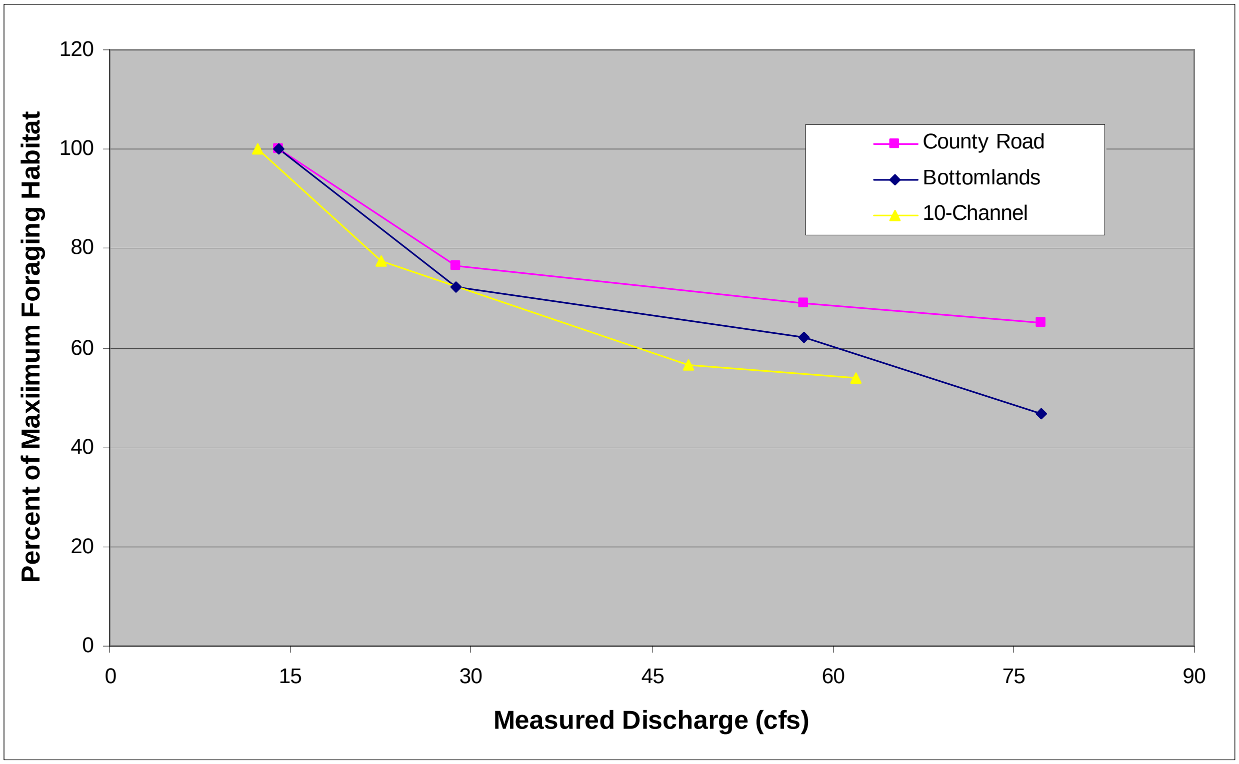


Figure 10. Percent of maximum foraging habitat (ft^2) versus measured flow (cfs) for three Rush Creek mapping reaches located downstream of the Narrows, August 2008.

3.5 Rush Creek – Habitats in Upper Rush Mapping Section

The Upper section of Rush Creek was selected for habitat mapping because the Movement Study revealed that large brown trout radio-tagged in the MGORD migrated downstream into this reach for fall-spawning and winter-holding. Although our reach selection for the instream flow needs assessment (and ultimately flow recommendations) was focused downstream of the Narrows where we suspect continued improvement in habitat will occur, we acknowledged that any instream flow needs identified below the Narrows should consider effects to habitat currently used by the "large trout" population which resides in the MGORD and seasonally utilizes habitat within the Upper section. When compared to the four mapping reaches located below the Narrows, the Upper Rush mapping reach contained relatively low amounts of both winter holding and foraging habitats, due to the relative lack of pool units in this steeper reach of Rush Creek (Figures 6 and 9).

In the Upper Rush mapping reach, winter holding habitat that met criteria was most available at the measured discharge of 33.5 cfs and dropped by nearly 40% at the next higher measured discharge of 64.0 cfs (Table 6 and Figure 11). The amount of available winter holding habitat then increased by 14% between the measured discharges of 64.0 and 94.2 cfs (Table 6 and Figure 11); due primarily to off-channel alcoves that were depth-limited at all but the highest test flow release.

In the Upper Rush mapping reach, foraging habitat that met criteria was most available at the lowest measured discharge of 17.9 cfs and dropped by 23% and 58% on the next two measured discharges of 33.5 cfs and 64.0 cfs, respectively (Table 6 and Figure 11). Similar to winter holding habitat, the depth-limited alcoves became available as foraging habitats at the highest test flow release and their availability resulted in a 3.5 % increase in available foraging habitat (Table 6 and Figure 11). As foraging habitats, these alcoves lacked main channel flows that provide reliable delivery of drifting food items to feeding trout.

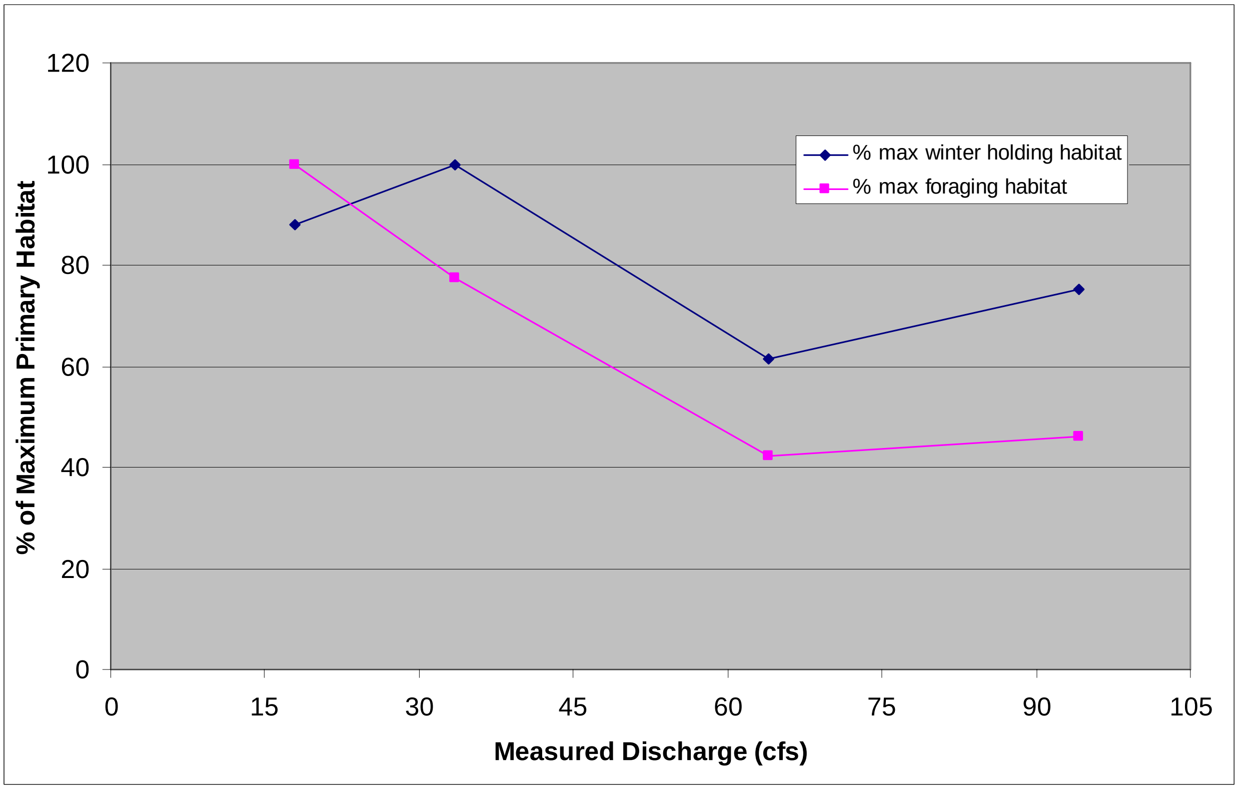


Figure 11. Percent of maximum foraging habitat (ft^2) and maximum winter holding (ft^2) versus measured flow (cfs) for the Upper Rush Creek mapping reach, August 2008.

3.6 Lee Vining Creek – Overview of Field Mapping

The habitat mapping on Lee Vining Creek occurred on April 30 – May 5, 2009. The order of test flow releases was: 12 cfs, 20 cfs, 28 cfs, 37 cfs, and 54 cfs. Each test flow was held to allow for a single day of mapping. The mapping of adult brown trout winter holding and foraging polygons onto graph paper allowed the pool-mapping team to concentrate on taking accurate depth and velocity measurements, as opposed to struggling with polygon placement on the poor quality photographs.

The M&T field crew measured stream discharge during each test flow at a single mainstem location upstream of the County Road Ford. However, due to potential measurement error from coarse streambed material at the measurement location and flow loss to varying side channels, all habitat-flow relationship curves were constructed using the DWP test flow release on the X-axis.

3.7 Lee Vining Creek – Winter Holding Habitat

Relative to summer foraging habitat, the mapped reaches of Lee Vining Creek supported little winter holding habitat (Figure 12). Both types of habitat were most available at the lowest test flow of 12 cfs (Figure 12). At 12 cfs, there was 3,039.5 ft^2 of total summer foraging habitat and 637.2 ft^2 of winter holding habitat (Figure 12).

Winter holding habitat was then plotted separately because the large Y-axis scale on the combined graph made it difficult to observe the differences in winter holding habitat availability versus test flow (Figure 13). Although winter holding habitat that met criteria for the total study area was greatest at 12 cfs and dropped by nearly 21% between 12 and 20 cfs; approximately 4% more winter holding habitat was available at 28 cfs than at 20 cfs (Figure 13). When the total study area was segregated into reaches "upstream and downstream" of the County Road Ford, the increase in total winter holding habitat between 20-28 cfs was due to the "downstream of County Road" habitat-flow relationship curve (Figure 13). The "downstream of County Road" composite habitat-flow relationship curve was heavily influenced by a single habitat unit (#13); a large pool located approximately 500' upstream of the Mono Lake delta (Figure 14). Winter holding habitat increased within this large pool at 28 cfs due to depth limitations at 12 and 20 cfs that then met depth criterion at 28 cfs; however as test flows increased beyond 28 cfs excessive velocities decreased available winter holding habitat in this pool unit (Figure 14).

The amount of available winter holding habitat within the "upstream of County Road" mapping reach was also heavily influenced by a single habitat unit, Class-5 Pool #1 (Figure 15). Unlike Unit #13, the Class-5 Pool #1 lost available winter holding habitat at each test flow increase, with the largest drop (42%) in habitat occurring between the 20 and 28 cfs test flow releases (Figure 15). As test flows increased, the winter holding polygons became shorter and narrower as velocities increased. The Class-5 Pool #1 was a long (75 ft) narrow pool with extensive undercut banks along both banks (2 -5 ft deep along the left-bank) with a residual maximum depth of 3.0 ft. This Class-5 pool that was relatively long and narrow with undercut banks may be the desired, future condition of pools in Lee Vining Creek as riparian vegetation continues to mature and create more competent banks for high flows to scour against and create undercut bank habitats.

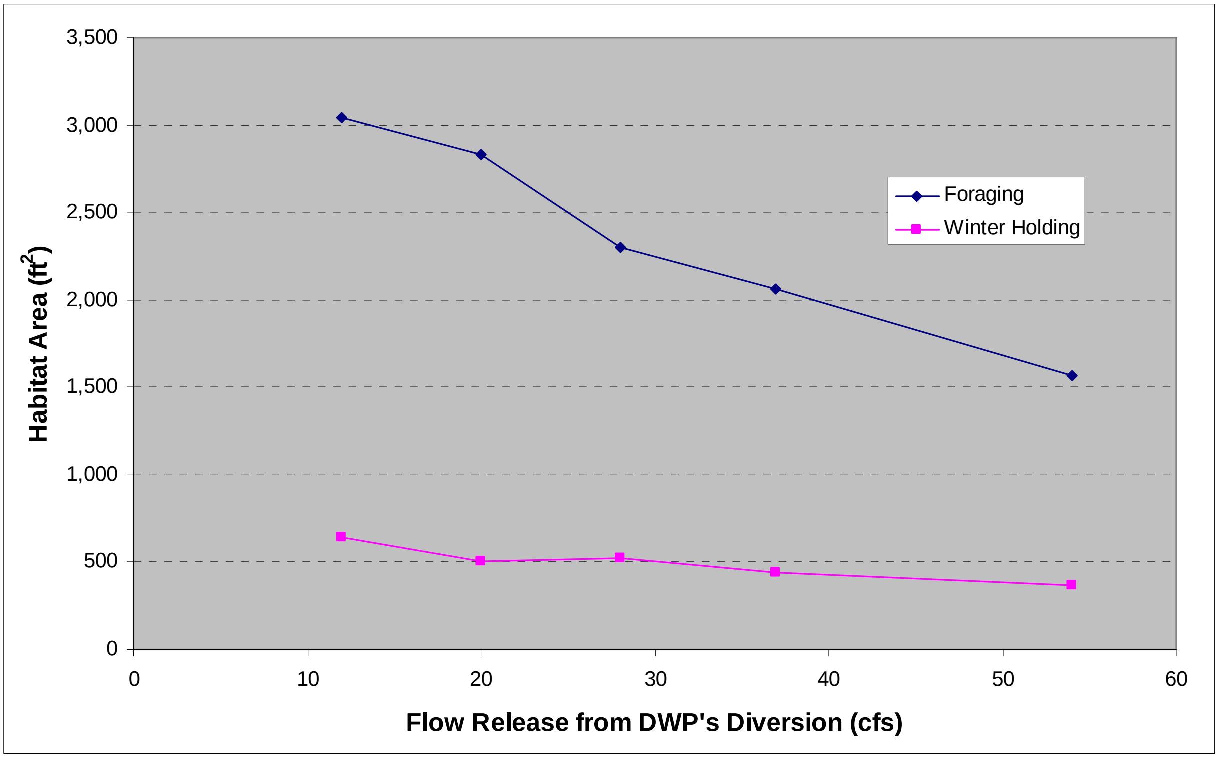


Figure 12. Composite habitat-flow relationship curves of adult brown trout winter holding and foraging habitats for Lee Vining Creek, April 2009.

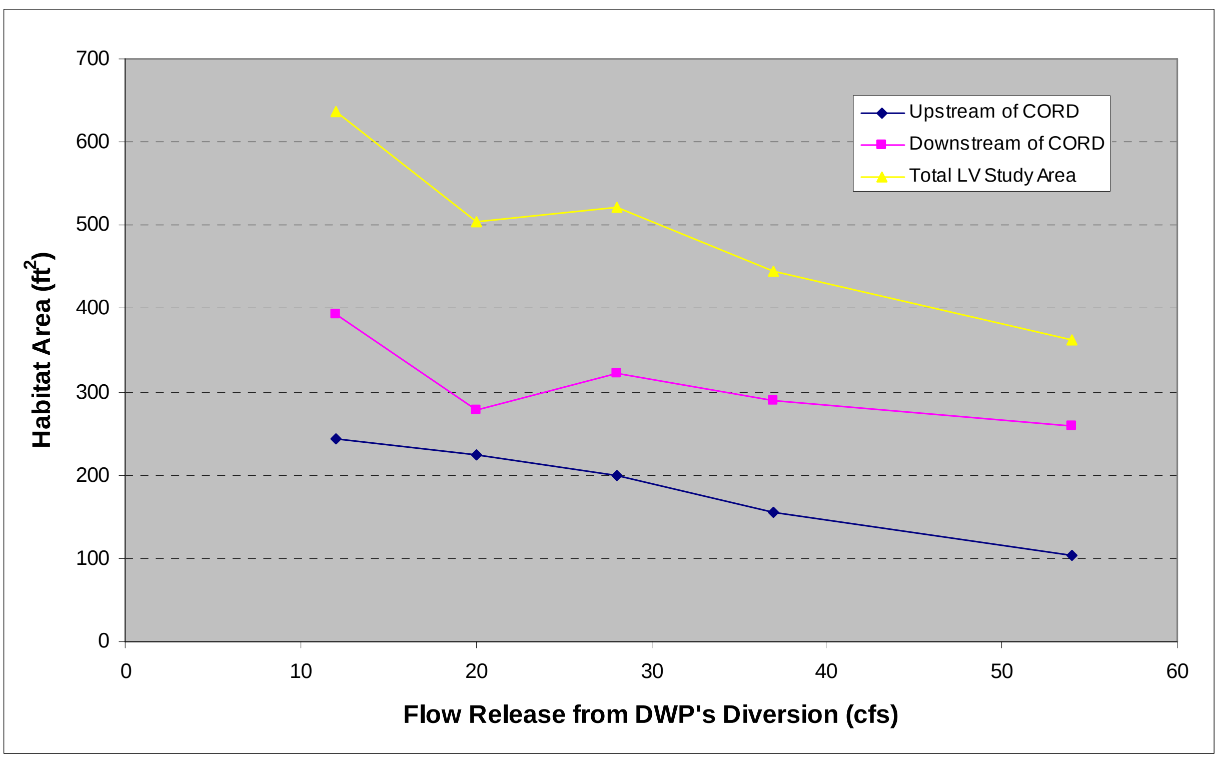


Figure 13. Winter holding brown trout habitat-flow relationship curves for units mapped upstream of the County road crossing, downstream of the County road crossing, and for the entire Lee Vining Creek study area, April-May 2009.

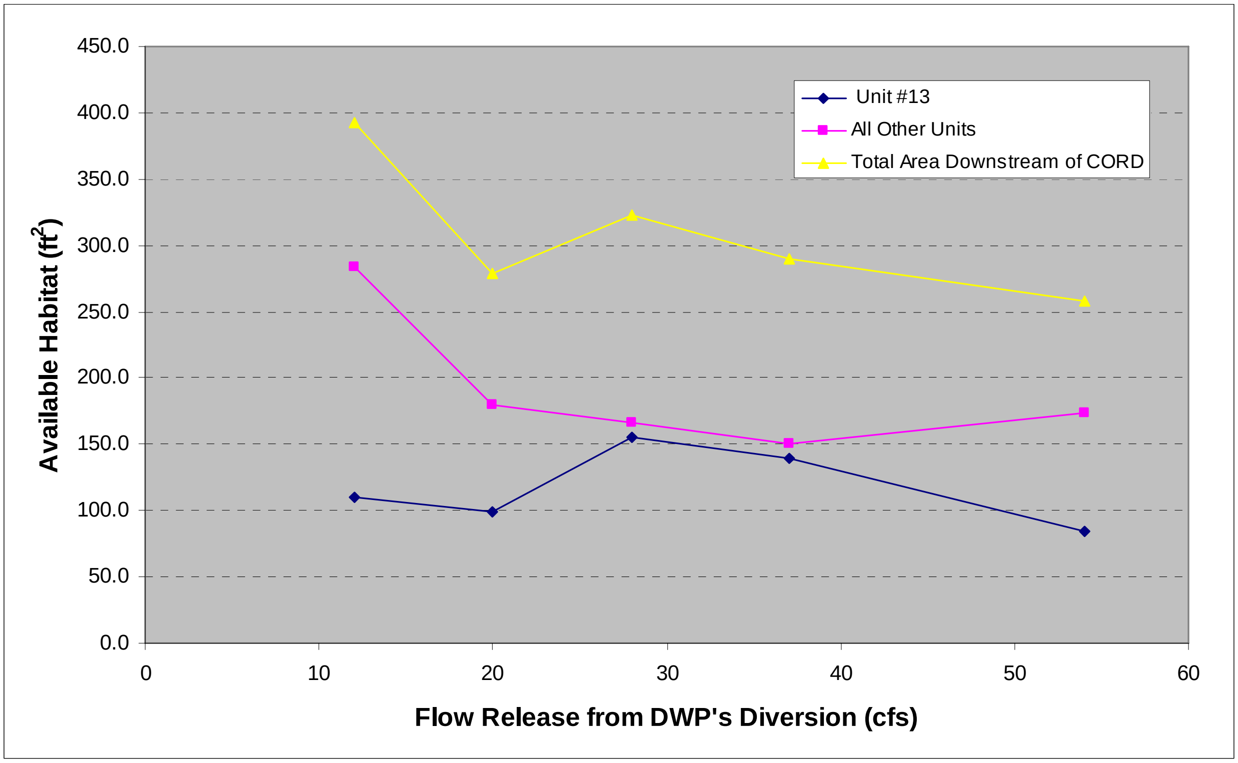


Figure 14. Lee Vining Creek brown trout winter holding habitat-flow relationship curves for units downstream of County Road, April-May 2009.

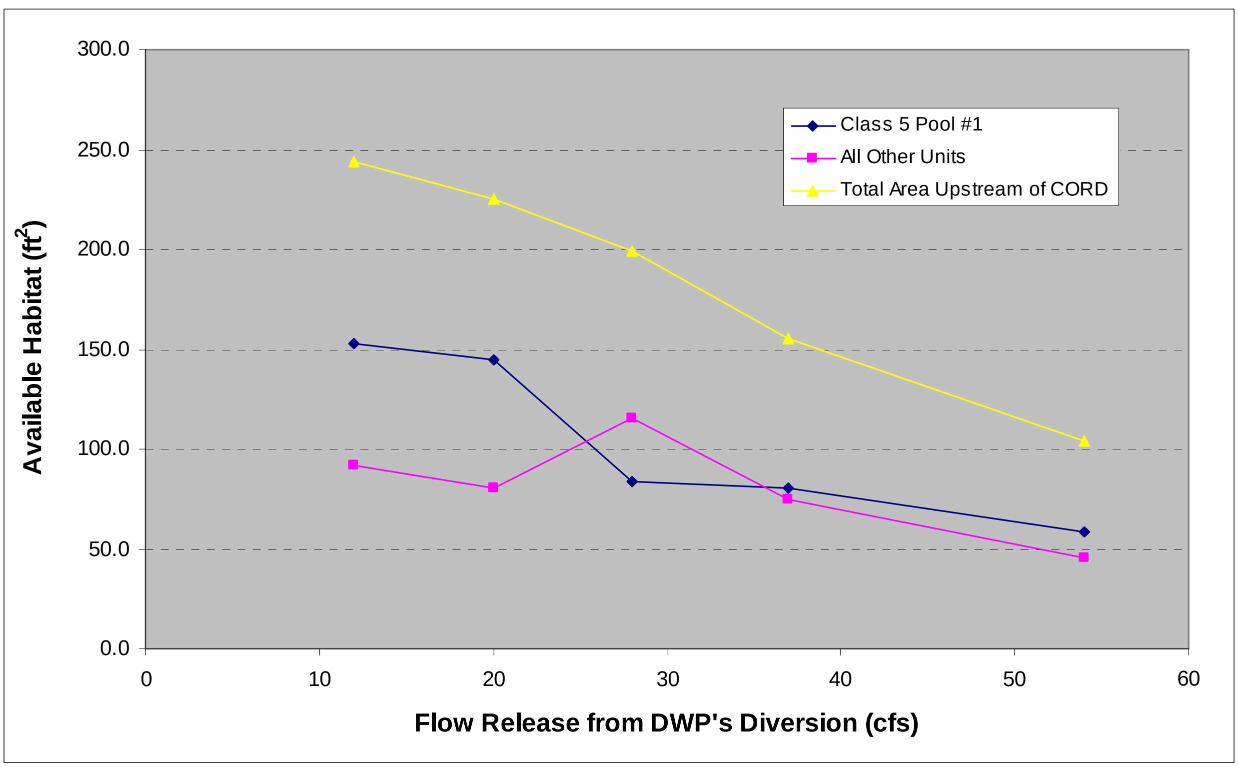


Figure 15. Lee Vining Creek brown trout winter holding habitat-flow relationship curves for units upstream of County Road, April-May 2009.

3.8 Lee Vining Creek – Foraging Habitat

Foraging habitat in Lee Vining Creek was present at all five test flows and was comprised of polygons of at least 12.0 ft^2 in primary pool and run/glide units and of polygons of at least 9.0 ft^2 in pocket pools (Figure 16). When all habitat units were combined, the amount of available foraging habitat was greatest (3,039.5 ft^2) at the lowest test flow of 12 cfs and decreased as flow increased (Figure 16). At the 54 cfs test flow the amount of available foraging habitat was 1,567.07 ft^2, approximately 50% of the maximum amount available at the 12 cfs test release flow (Figure 16).

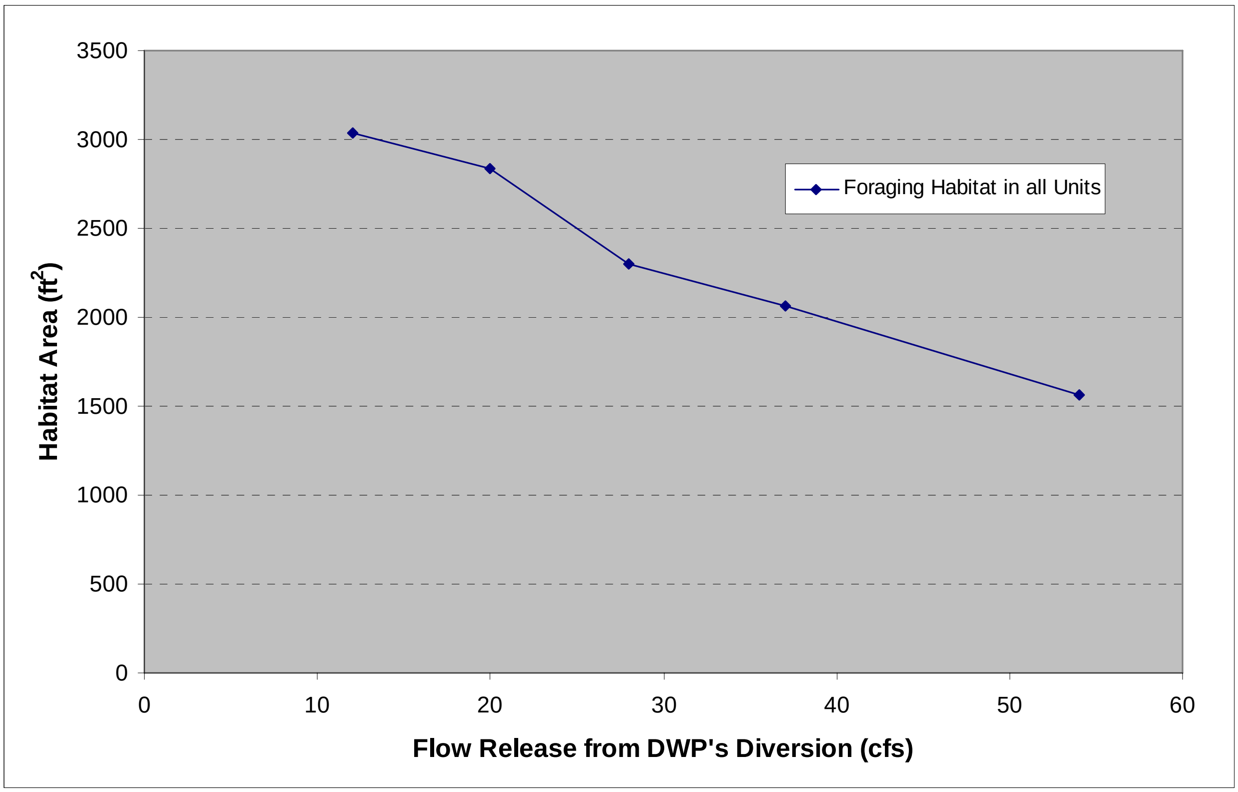


Figure 16. Lee Vining Creek brown trout habitat-flow relationship curve for foraging habitat in all habitat unit types, April-May 2009.

A more informative view of available foraging habitat was revealed by displaying pocket pool polygons separately from primary pool polygons (Figure 17). Between 12 cfs and 20 cfs, pocket pool foraging habitat area increased from 557.7 ft^2 to 966.3ft^2 (Figure 17). At the 28 cfs test flow, pocket pool foraging habitat area dropped by 25% to 730.0 ft^2 (Figure 17).

At the 20 cfs test flow, the foraging polygons within pocket pools accounted for 34% of the total available foraging habitat. The 20 cfs test flow also supported the greatest number of individual pocket pool polygons and the most pocket pool polygons greater than 20 ft^2 in size (Table 7). More, and larger, individual pocket pool units create more individual territories for brown trout to occupy. Pocket pool frequency (number of units per length of channel) also decreased in a downstream direction as channel gradient decreased.

The locations of pocket pools that met our foraging criteria also changed at the various test flows, and these varying locations may have ecological significance in regards to providing high-quality forage areas as well as escape cover for adult trout. At lower test flows, many of the mapped pocket pools were located on the downstream side of exposed boulders, with few units located near the banks due to lack-of-depth. As flows increased, the pocket pools located behind mid-channel boulders decreased in frequency as these boulders were inundated with fast flowing water (Figures 18-20). At 54 cfs, most of the units that met our pocket pool criteria were, in fact, edge-water habitats located on channel margins (Figures 18-20). Due to the proximity of the stream bank, these units only offered a single feeding lane (as opposed to two feeding lanes at a mid-channel unit) and appeared to lack the avoidance/escape cover of mid-channel pocket pools.

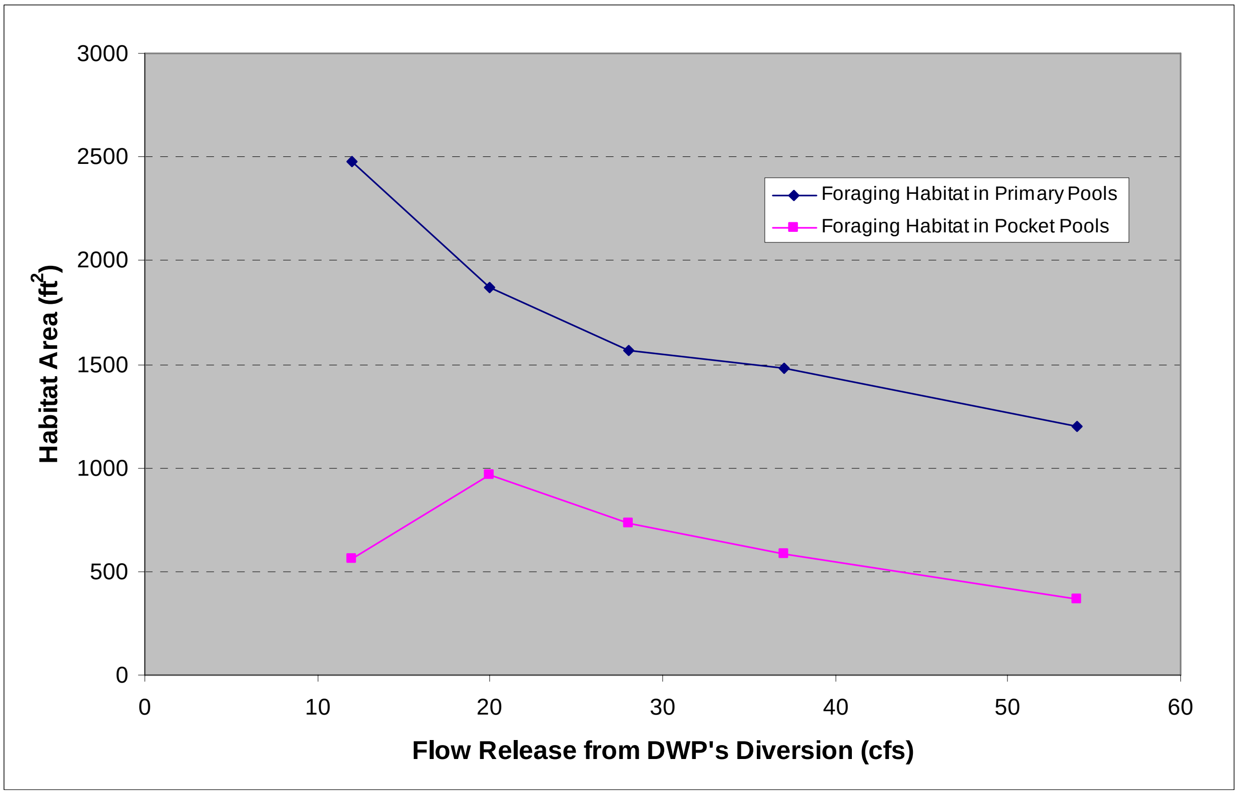


Figure 17. Lee Vining Creek brown trout foraging habitat-flow relationship curves for pool units and pocket pools, April-May 2009.

Table 7. Total area (ft^2) and number of individual units of summer foraging habitat mapped within Lee Vining Creek pocket pools at five test flows.

Test Flow (cfs)	Total Area (ft^2)	Total Number of Individual Polygons	Number of Polygons >20 ft^2
12	557.7	34	7
20	966.3	53	14
28	730.0	39	11
37	585.5	32	10
54	370.0	25	3

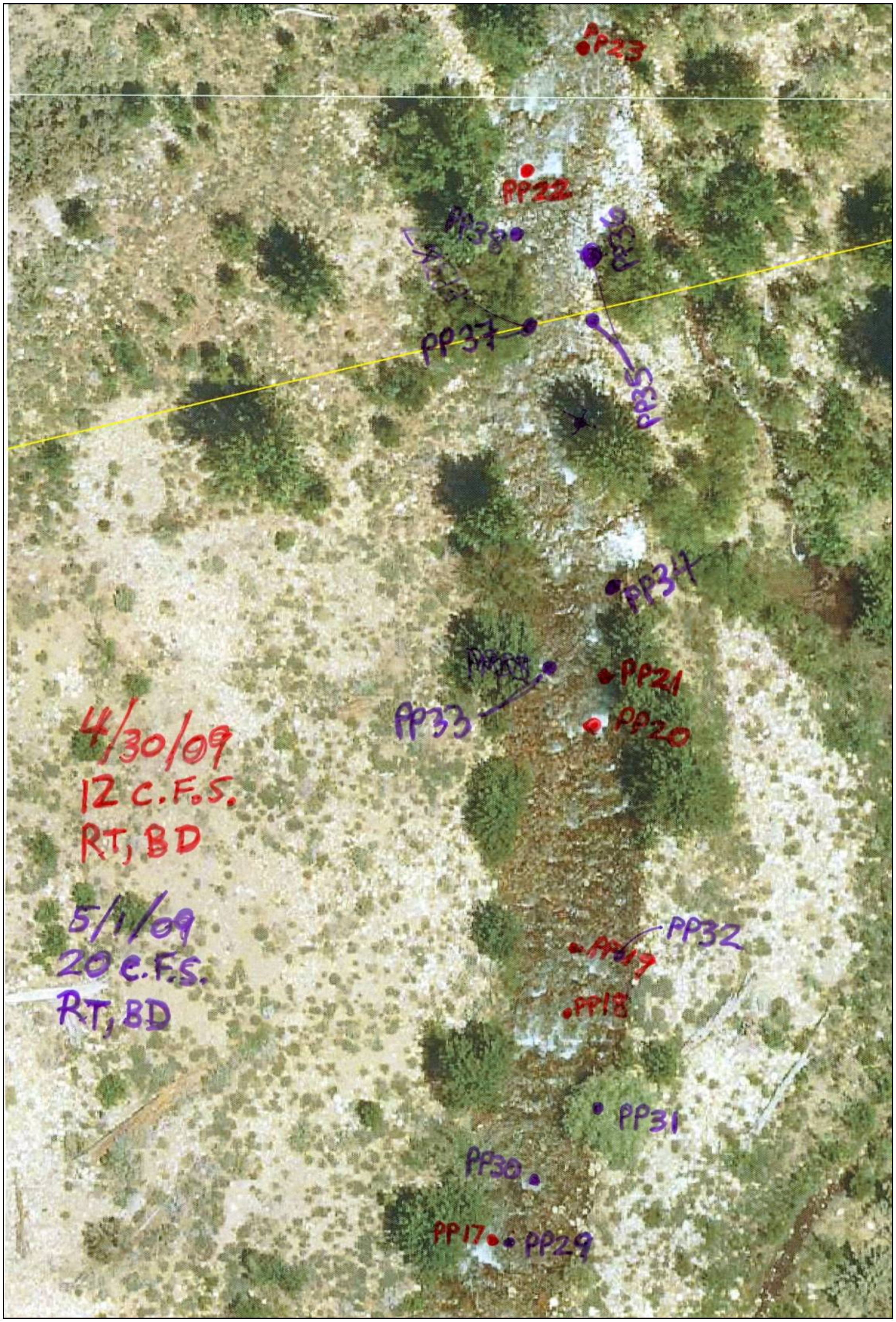


Figure 18. Pocket pool polygon locations on Lee Vining Creek at 12 cfs and 20 cfs test flows. Scale: 1" = 25.

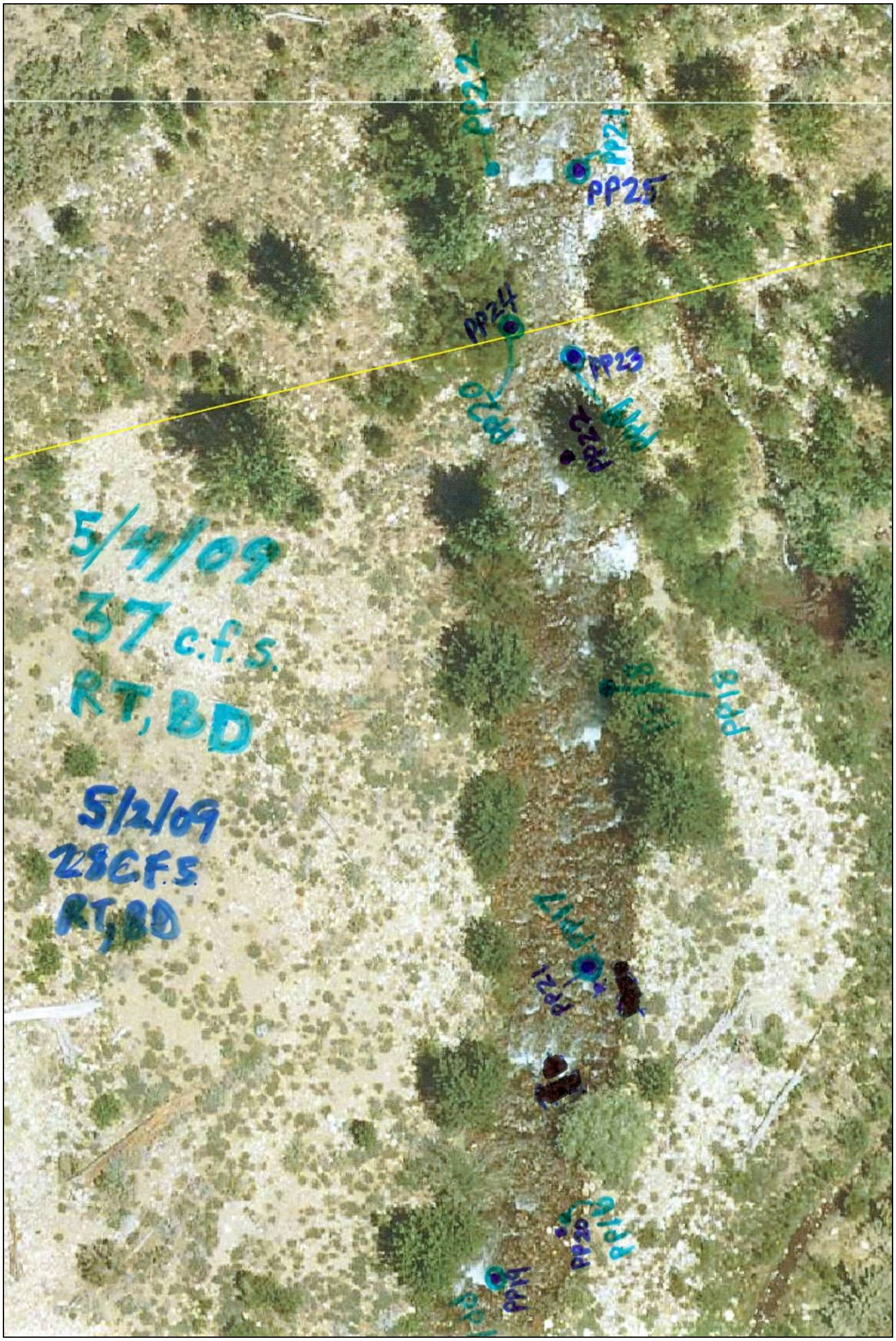


Figure 19. Pocket pool polygon locations on Lee Vining Creek at 28 cfs and 37 cfs test flows. Scale: 1” = 25.

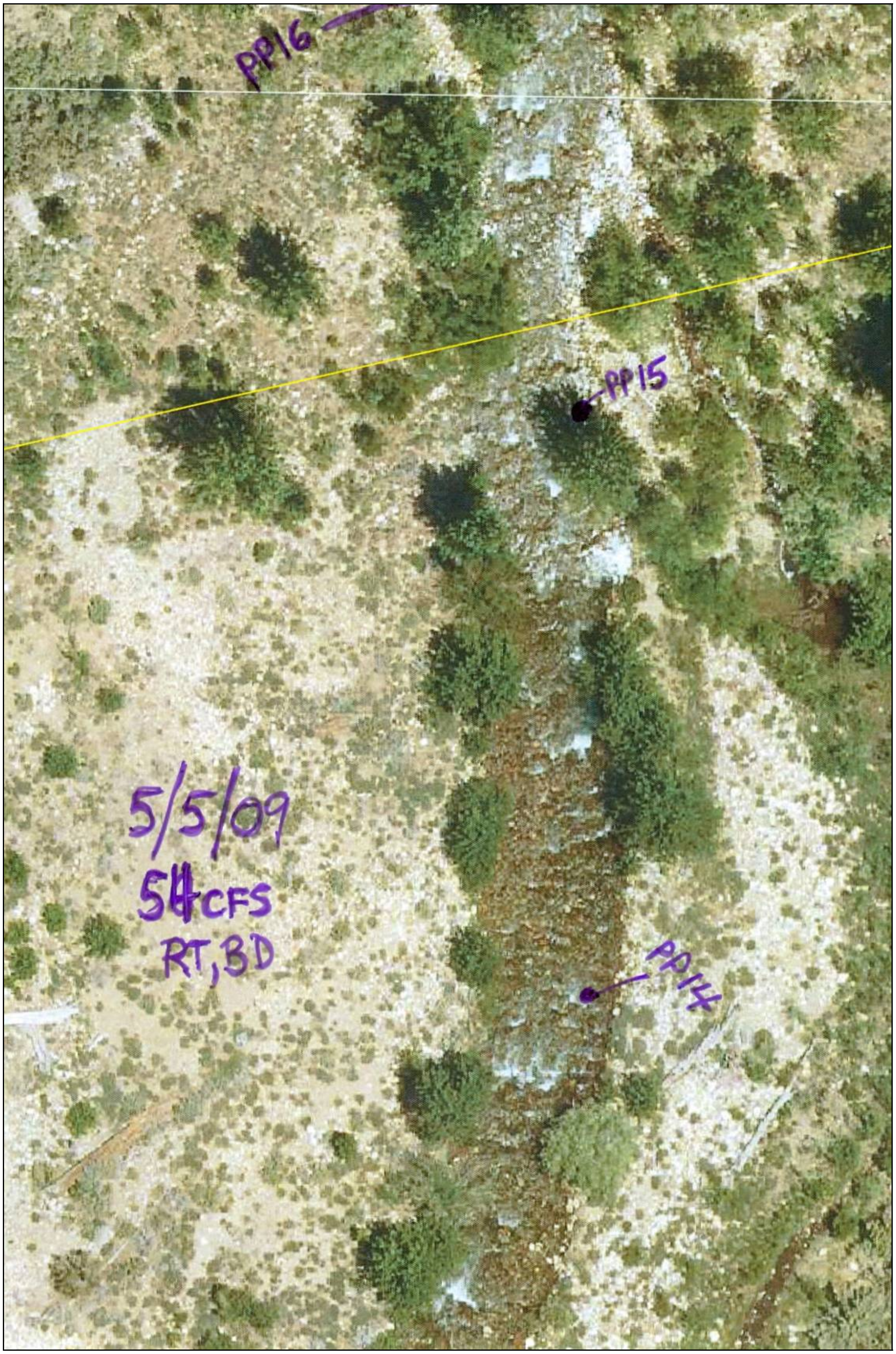


Figure 20. Pocket pool polygon locations on Lee Vining Creek at the 54 cfs test flow. Scale: 1” = 25.

3.9 Rush Creek – BMI Mapping Results

The Rush Creek mapping reaches varied in channel slope, cross section dimensions, distribution of meso-habitat units, and proportion of the MGORD flow release each reach received. Despite these reach differences, BMI habitat curves showed very similar, although not identical, relationships to discharge. To standardize our analyses and allow comparisons to trout habitat mapping, we plotted BMI habitat area against the MGORD discharge instead of the reach-specific measured discharge.

The BMI habitat area composite curves (Figure 21) summed all habitat areas for each test flow for each reach, and plotted habitat area vs. discharge. The composite curves showed an increase in combined BMI habitat area in all five reaches between 15, 30, and 45 cfs. In three of the five mapping reaches (Upper Rush, 10-Channel, Bottomlands), BMI habitat area reached an asymptote at 45 cfs. In these three reaches BMI habitat increased only slightly (10-Channel) or decreased slightly (Upper Rush, Bottomlands) as flow changed from 45 to 60 cfs, and from 60 to 90 cfs. Only two reaches (lower Rush, County Road) continued to gain BMI habitat area with increased flows from 60 cfs to 90 cfs. These habitat rating curves highlight the differing hydraulic dynamics between the two mainstem reaches: the higher slope and roughness in the upper Rush Creek reach translated into deeper main channel flows compared to the reaches below the Narrows, in which the lower channel gradient, and finer substrate particle size translated into smaller incremental stage changes.

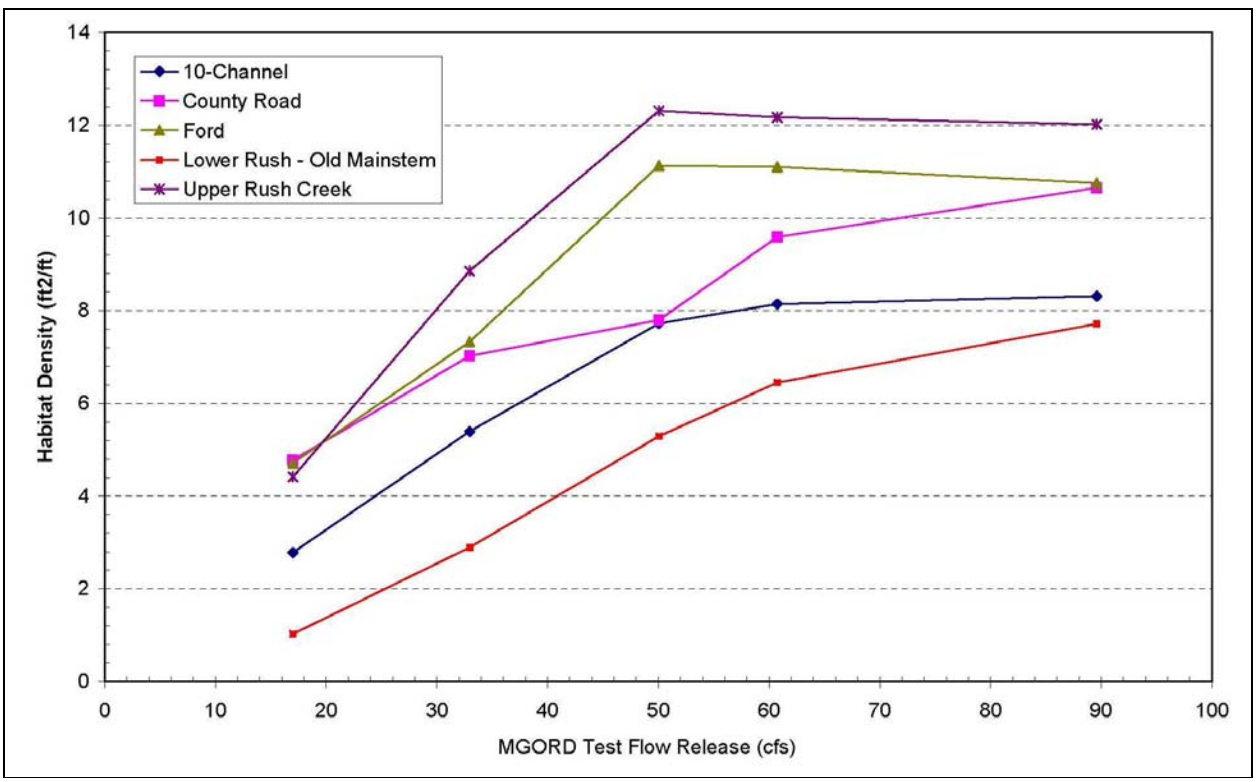


Figure 21. Composite BMI habitat rating curves for five reaches mapped on Rush Creek in August 2008.

We noted a trend in the field that was confirmed by our habitat maps: as flow increased from 45 to 60 cfs and from 60 to 90 cfs, BMI habitat expanded along the stream margin and gravel bar edges governed by the velocity criterion, and BMI habitat decreased in mid-channel governed by the depth criterion. An example of our mapping from the Rush Creek Bottomlands reach illustrates these changes in habitat area with flow (Figure 22). Exceedence of the 1.5 ft depth threshold does not signify that BMI habitat would be bad, only that it may not be as hydraulically complex and/or as biologically productive. Substrate area that met our particle size criterion was the ultimate limitation to productive riffle area.

In addition to the composite habitat rating curves, individual habitat rating curves were plotted for two reaches on Rush Creek: Upper Rush and the Bottomlands. Evaluation of individual habitat rating curves is a critical aspect of our analysis to identify instream flow needs. The individual curves demonstrate an important feature of BMI habitat captured by our habitat mapping methods: the distribution and abundance of habitat patches varied longitudinally along each reach, and individual habitat patches also differed in response to changes in discharge. The composite curves do not reveal this variability. To generate individual rating curves, each reach was divided into multiple sub-units at the riffle crest or thalweg cross-over. Sub-units were thus typically composed of an alternate bar unit (i.e., one pool-riffle sequence). The Upper Rush Creek reach had 5 sub-units; the Bottomlands reach had 13 sub-units. These two reaches had the highest abundance of BMI habitat of the five mapping reaches.

In the Upper Rush Creek mapping reach (Figure 23a), the individual curves were similar to the composite curves: BMI habitat abundance increased from 15 to 45 cfs for all five of the sub-units. However, trends were different for the 60 and 90 cfs flow releases, with two subunits continuing to increase (sub-units 1, 5), two sub-units decreasing (3, 4), and one unit remaining static (2). In the Bottomlands reach, several sub-units containing long riffles (sub-units 3, 4, 10, and 12) dominated BMI habitat area, and each showed a sharp increase in area when flow increased from 30 to 45 cfs (Figure 23b). These large sub-units dictated the shape of the composite curve (Figure 21), whereas the remaining sub-units (adjusting the y-axis scale for better resolution) showed a much higher degree of variability in response to changing discharge (Figure 23c). Curves from several sub-units (2, 5, 11) were flat, showing little or no response to change in discharge. Two curves (7, 8) declined in area above 30 cfs. Others (1, 6, 9) mirrored the dominant units' trend, reaching an asymptote at the 45 to 60 cfs discharge range.

As flow increased from 45 to 60 cfs and from 60 to 90 cfs, BMI habitat expanded along the stream margin and gravel bar edges governed by the velocity criterion, and decreased in mid-channel BMI habitat governed by the depth criterion. An example of our mapping from the Rush Creek Bottomlands reach illustrates these changes in habitat area with flow (Figure 22). Exceedence of the 1.5 ft depth threshold did not signify that BMI habitat would be bad, only that it was likely not as hydraulically complex and/or as biologically productive. Substrate area that met our particle size criterion was the ultimate limitation to productive riffle area.

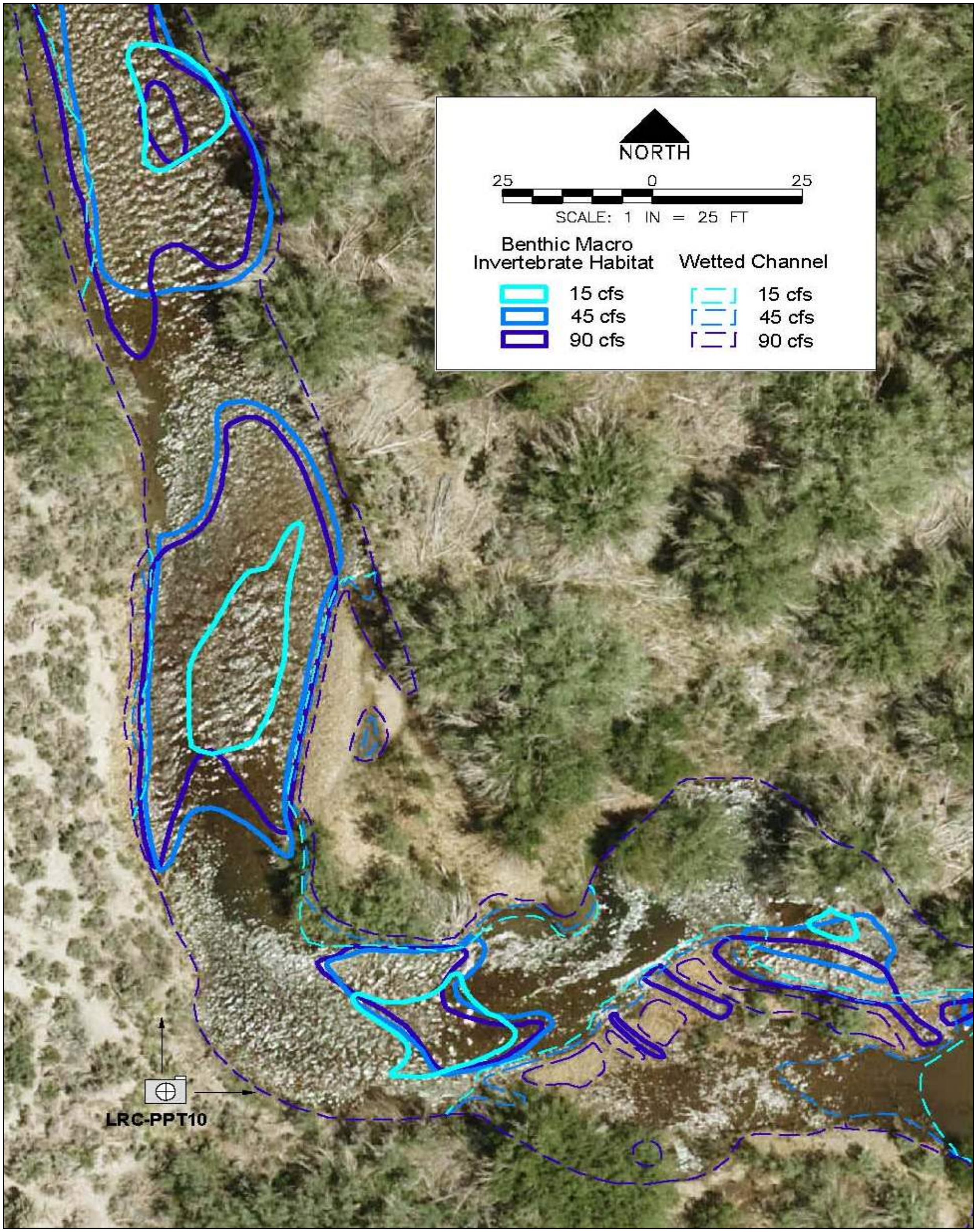
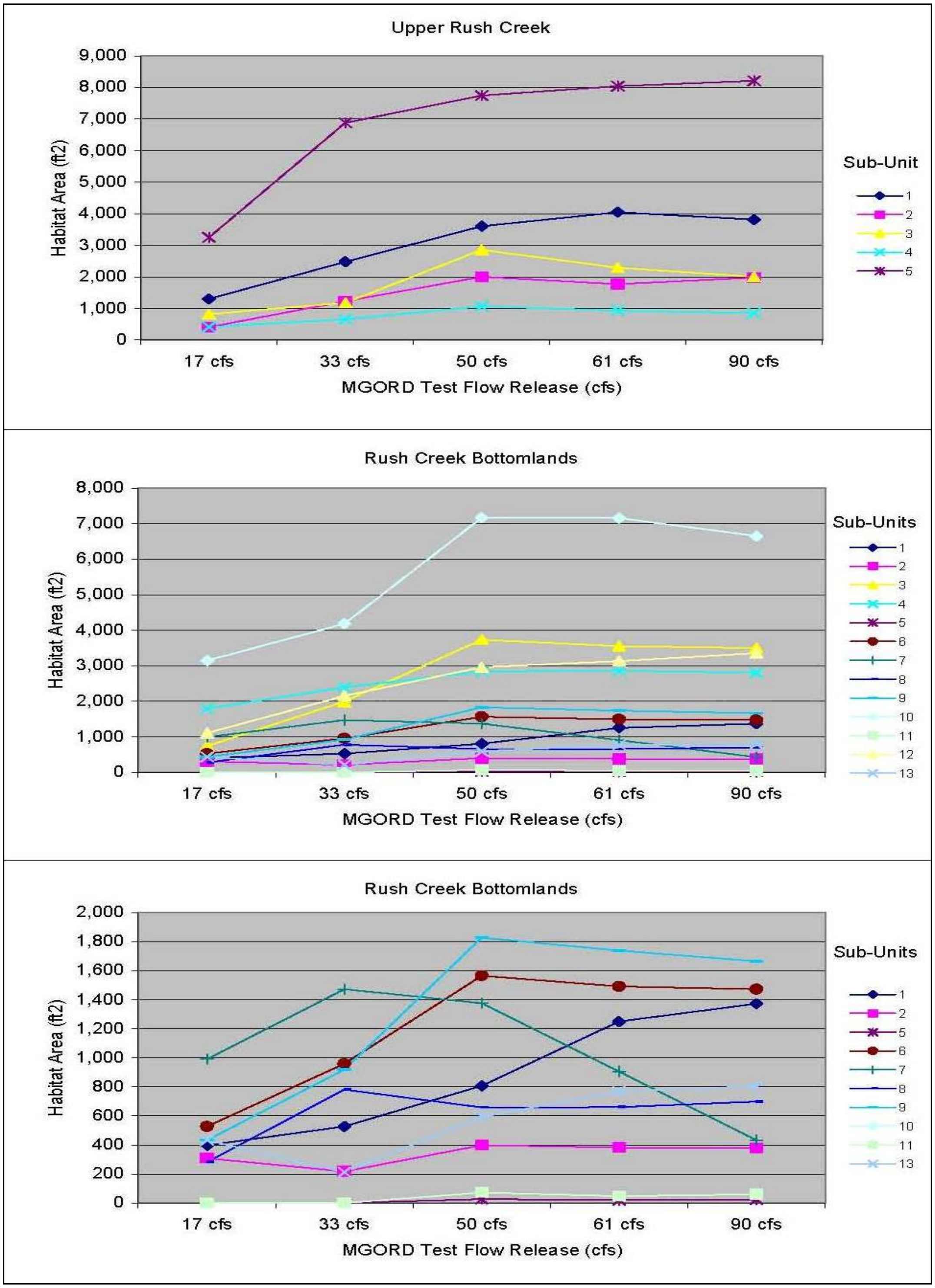


Figure 22. Example habitat map showing three of the five BMI polygons mapped on Rush Creek in the Bottomlands reach. Note the 15 cfs mid-channel polygon at the top of the photo was not mapped as habitat at the 90 cfs flow. In the bottom right of the photo, flow across the gravel bar provided BMI habitat at 90 cfs, but not the lower flows.



Figures 23a-c. Individual BMI habitat rating curves for Upper Rush and the Ford reaches on Rush Creek in August 2008. The upper chart (a) shows all sub-units in the Upper Rush reach; the middle chart (b) shows all sub-units in the Bottomlands reach, with habitat area dominated by several long riffles responding similarly to change in discharge. The lower chart (c) shows the Bottomlands reach with different y-axis scale, and more variable responses to change in discharge among remaining sub-units.

Stage changes recorded at our study site monitoring cross sections were compared to the BMI polygon mapping results as a way to extend the habitat rating curves beyond 90 cfs (McBain and Trush 2009). At the 90 cfs release, most riffle area remained under 1.5 ft deep. Monitored cross-sections also showed this. A 150 cfs stream-flow exceeds the 1.5 ft depth threshold within the mainstem channels for most riffle cross-sections.

We mapped the wetted edge of the channel onto the aerial photographs at each flow to compute riffle wetted area (in ft^2) as a function of discharge. We also computed the incremental increase in area of inundated depositional features (e.g., gravel bars), establishing the 15 cfs flow release as a baseline (i.e., assuming no inundation of depositional features at this flow). We plotted these two curves along with the BMI curves for the Rush Creek Bottomlands reach (Figure 24). The riffle area curve was relatively flat, with little change in trajectory, indicating the test flows had not reached an asymptote in riffle area. The inundated depositional features curve did surpass a threshold, in which the curve steepened between 45 and 60 cfs, after which the rate of increase in inundated area decreased. Finally, the BMI curve for the Rush Creek Bottomlands reach attained an asymptote at 45 cfs.

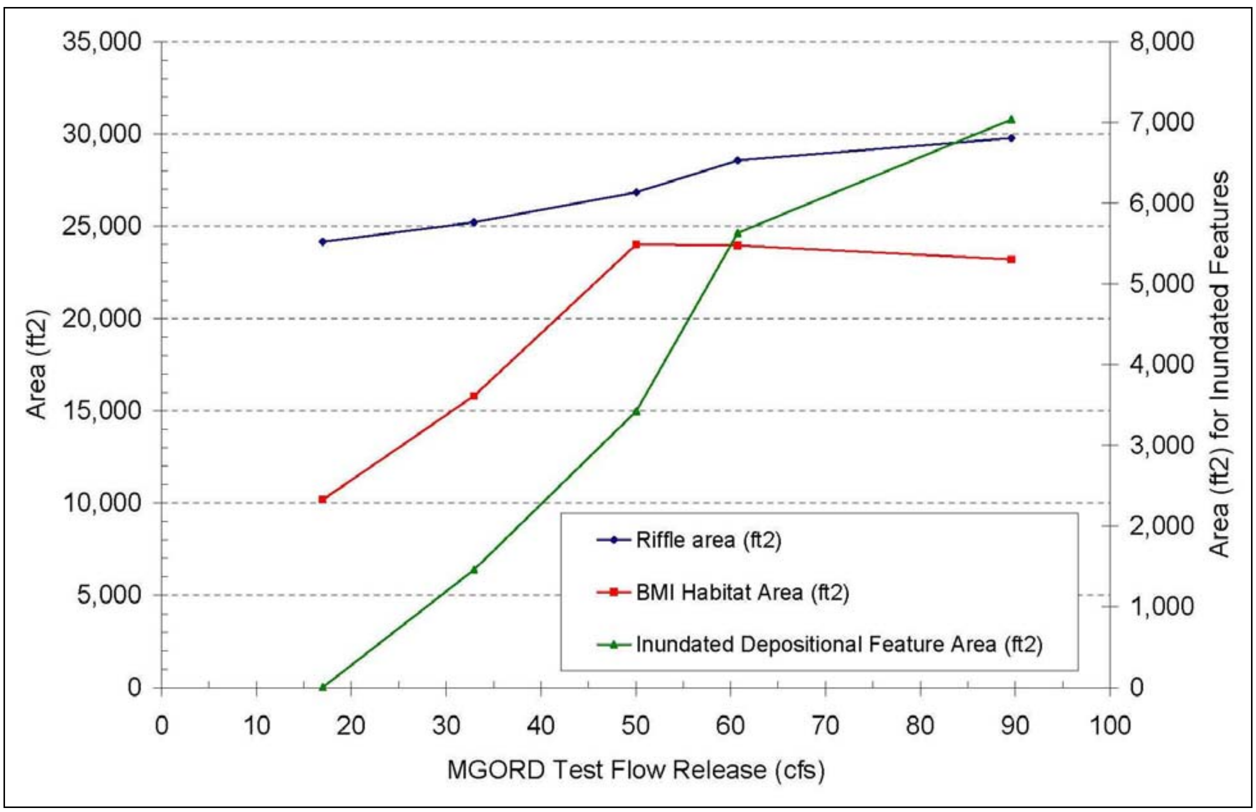


Figure 24. Composite curves showing BMI habitat area, riffle area as measured by increasing inundation of channel margins, and cumulative area of inundated depositional features. The relative shape of the curves and inflection points is the important feature of the chart.

We also mapped the locations of cut-off channels and side-channels that were flowing during the higher test flow releases. We noted a general threshold between 60 and 90 cfs in which many (but not all) alcoves, lateral scour channels, and side channels became wet and began flowing. In some cases, the side-channels are former mainstem channels. The ecological significance of these off-channel features was not quantified. However, several ecological functions are likely, including (1) providing brown trout fry rearing habitat, (2) importing large organic matter into the mainstem channel, especially willow and alder leaves having fallen the previous autumn, and (3) recharging shallow groundwater close to the mainstem channel. These features are drowned-out by streamflows inundating the entire floodplain (i.e., greater than 300 cfs).

Within our mapping reaches we established fifteen photo monitoring points, at which multiple-photo panoramic photographs were taken during each of the five test flows. An example composite photo from Photo Point #4 (from the 10-Channel) is shown in Figure 25.

Finally, we measured the thalweg depth at each riffle crest in the mapping reaches, to assess fish passage at each test flow. We also plotted the thalweg depths as a cumulative exceedence, which standardizes the data for comparison of depths along varying reach lengths (Figure 26).

Figure 25. Composite photo from Photo Point #4 located in the Rush Creek 10-Channel reach.

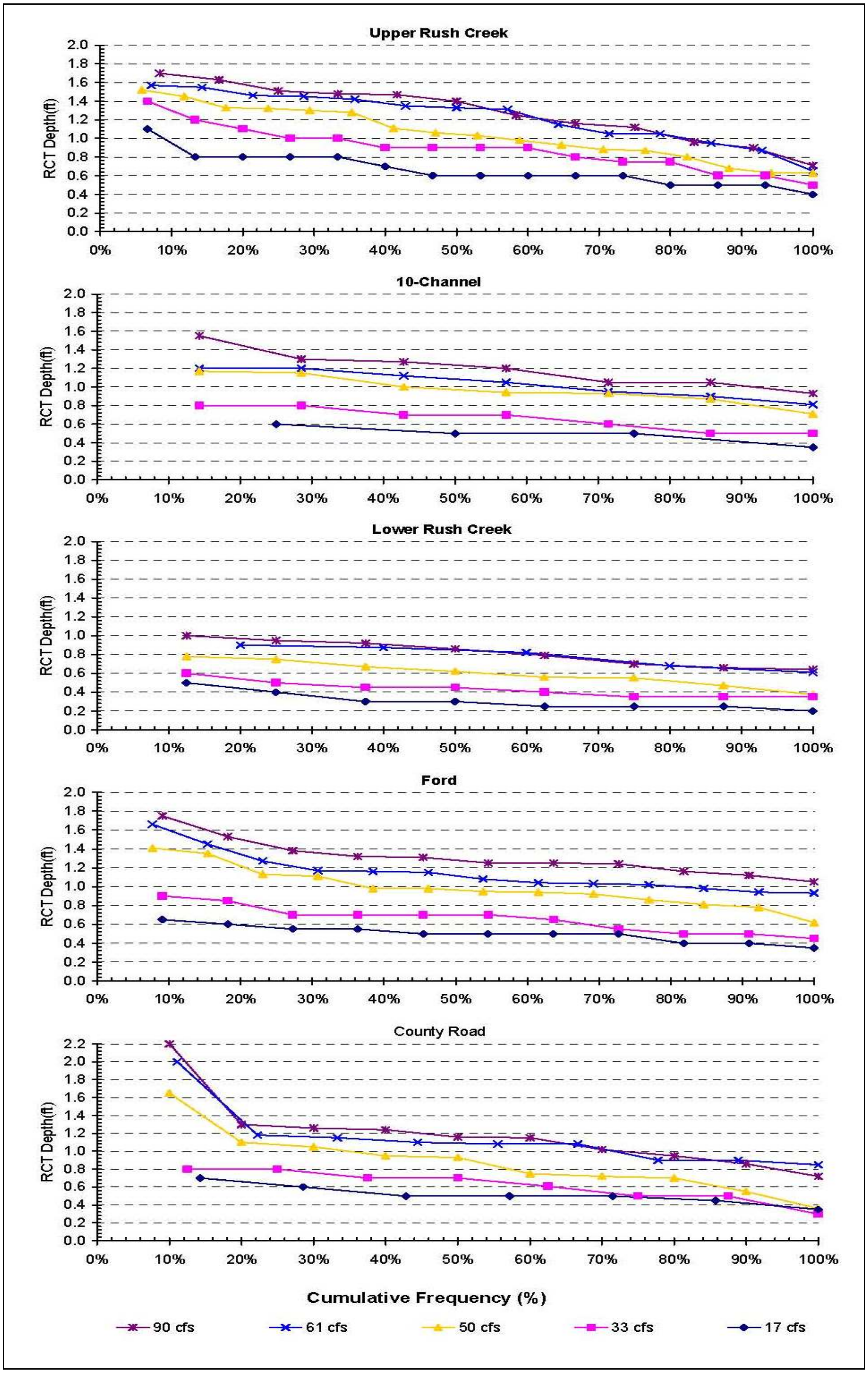


Figure 26. Riffle crest thalweg depths plotted as a cumulative exceedence to standardize the data for comparison of depths along varying reach lengths.

3.10 Lee Vining Creek – BMI Mapping Results

The Lee Vining Creek BMI mapping reach was characterized by long, relatively homogenous medium and high gradient riffles (reach-wide slope= 3.2%) with a coarse bed dominated by cobble and small boulder substrates. A typical section's D_{84} was 220 to 260 mm. The low flow channel was confined within steep alluvial banks. Lateral gravel or cobble bar features were few. Within the 1,371 ft long reach, four pools or pool-runs punctuated the continuous riffle. Stage height changed by approximately 0.1 to 0.2 ft for each test flow increment. With the exception of a few locations where the banks were less steep, channel widths varied very little with each test flow increment.

Several side-channels were present in the Lee Vining Creek mapping reach, including the A-1, A-3 (our mainstem mapping reach), and the A-4 channels, as well as short segments of braided channel (Figure 27). The A-1 side-channel and a small return channel remained flowing at the lowest test flow release of 12 cfs. At the 12 cfs flow release, the A4 Channel had no measurable flow at the downstream end, but began flowing at subsequent higher flow releases, with and 2.4 cfs measured at the 28 and 38 cfs flow releases. Discharge in the A4 Channel increased to 4.5 cfs at the 54 cfs release. The left bank braided side channels along the mainstem mapping reach remained dry or had seepage through the 38 cfs test flow, and finally exceeded the channel entrance threshold at 54 cfs (Figure 27).

The Lee Vining Creek BMI composite habitat-flow curve reinforced our field observations of the relative productivity of the range of test flows. The lower two test flow releases, 12 and 20 cfs, had the least abundant BMI habitat area of all test flows (Figure 28). During these two test flow releases, abundant shallow and slow pockets of water that did not meet our hydraulic criteria were observed along the mapping reach, mainly along the stream margins. Abundant BMI habitat was concentrated in a thin, continuous strip in the center of the channel. As discharge increased, BMI habitat polygons expanded toward the channel margins. The middle two test flows of 28 cfs and 38 cfs were asymptotic in terms of total area, but not identical in planform locations. Many pockets of good habitat at 28 cfs became too deep (typically) in mid-channel areas at 38 cfs, whereas polygons continued to expand and incorporate more area along margins. The final increment mapped from 38 to 54 cfs continued this trend of expanded BMI habitat toward the stream margins, with too-deep areas excluded in mid-channel, with one important additional feature. The infrequent sections of channel where polygons ended at 38 cfs (at the pool and pool-run units), became continuous BMI polygons at 54 cfs (Figure 29), thus pushing the total BMI habitat area to a maximum at 54 cfs. In other words, at 54 cfs pool and pool-run units became fast enough to meet our velocity criterion of $V>1.5$ ft/s.

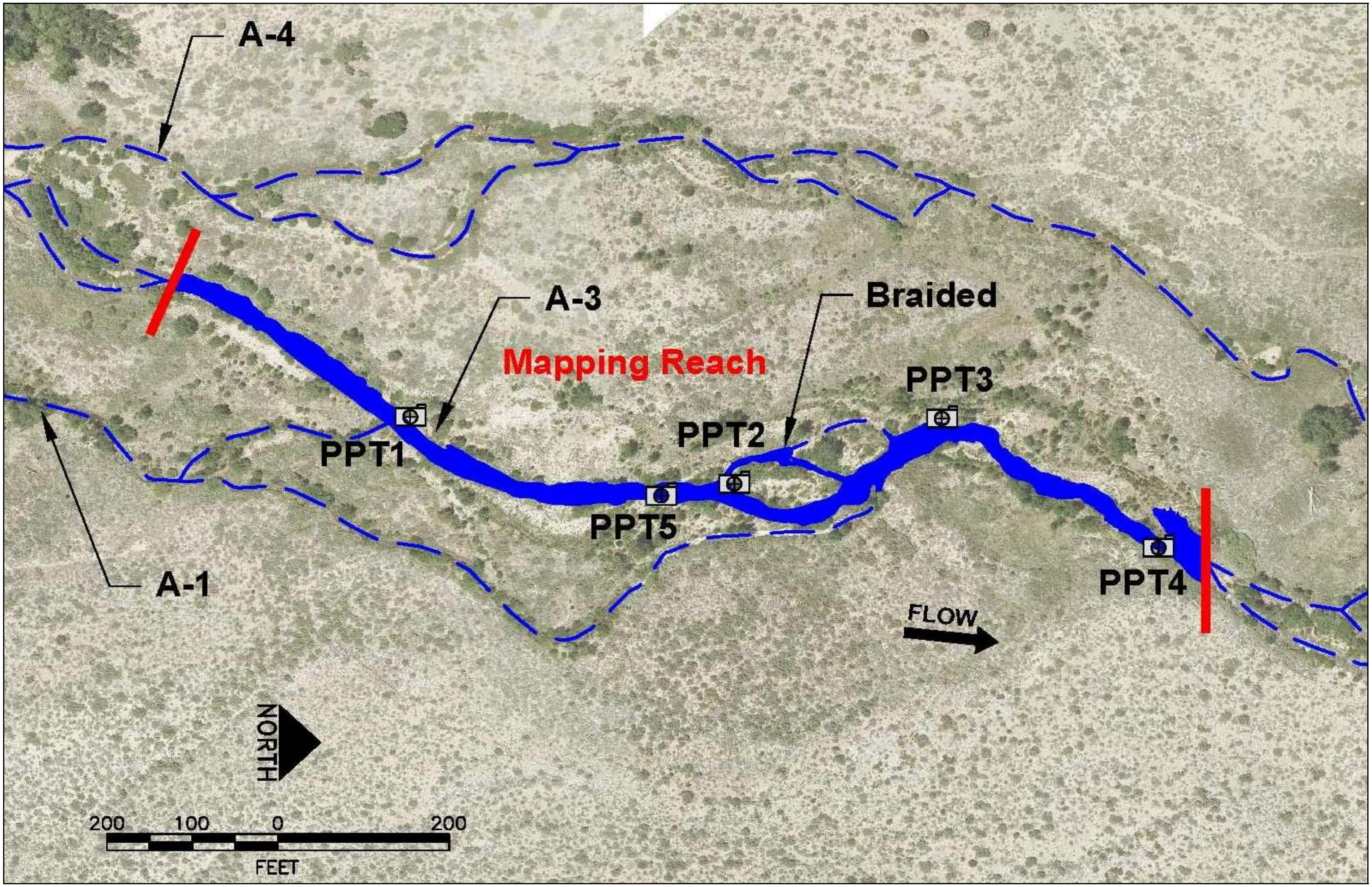


Figure 27. Aerial photograph from 2007 of the Lee Vining Creek corridor's network of mainstem channel, side channel, and braided channel sections. The A-1 Channel had flow at the lowest test flow release; other side channels began flowing during subsequent test flow releases.

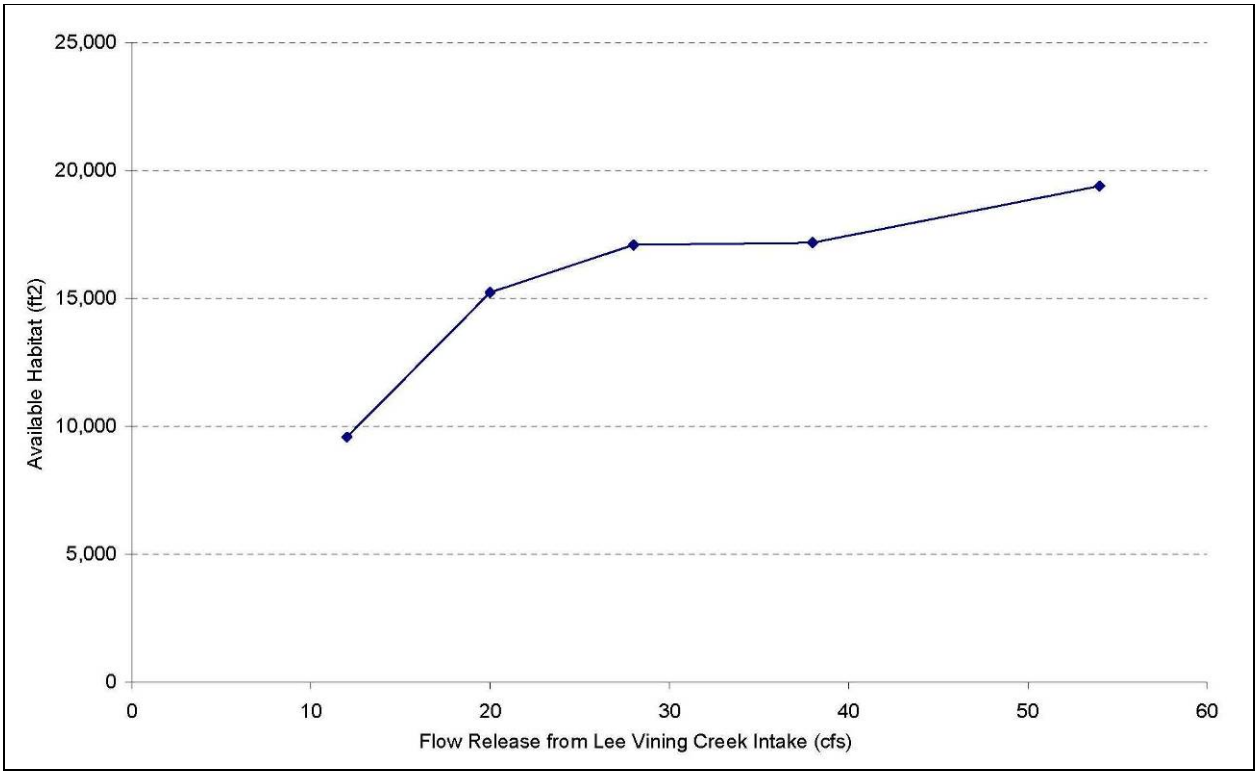
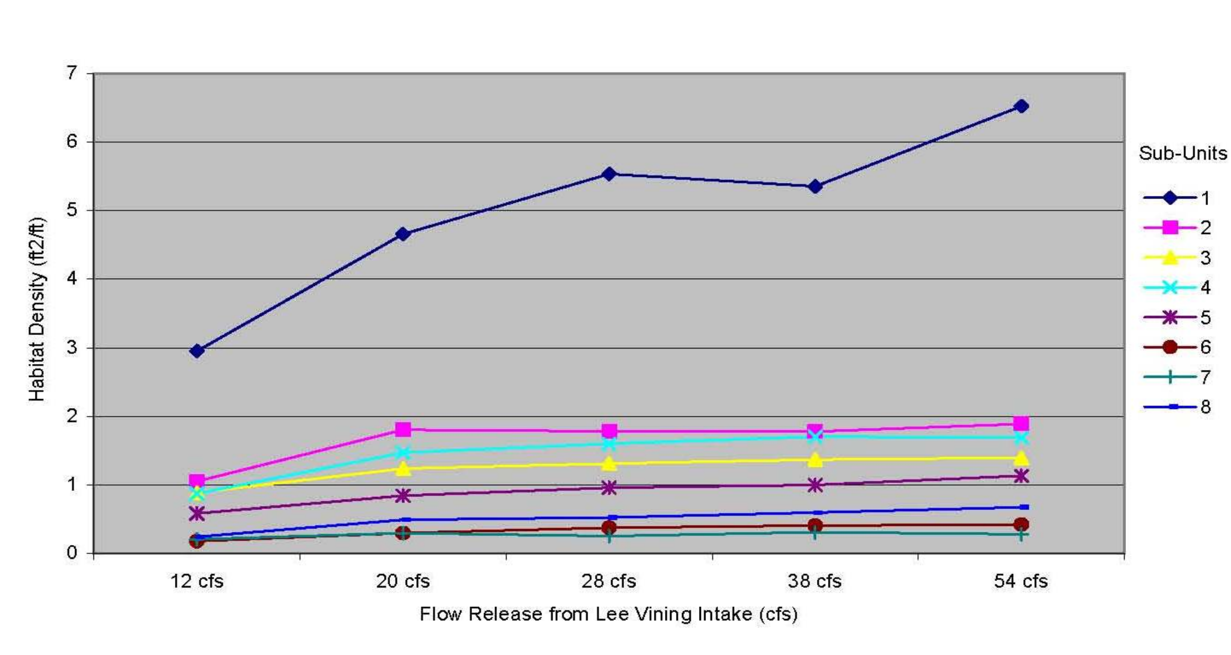


Figure 28. Composite BMI habitat rating curves for the Lee Vining Creek mainstem reach mapped in April and May 2009.



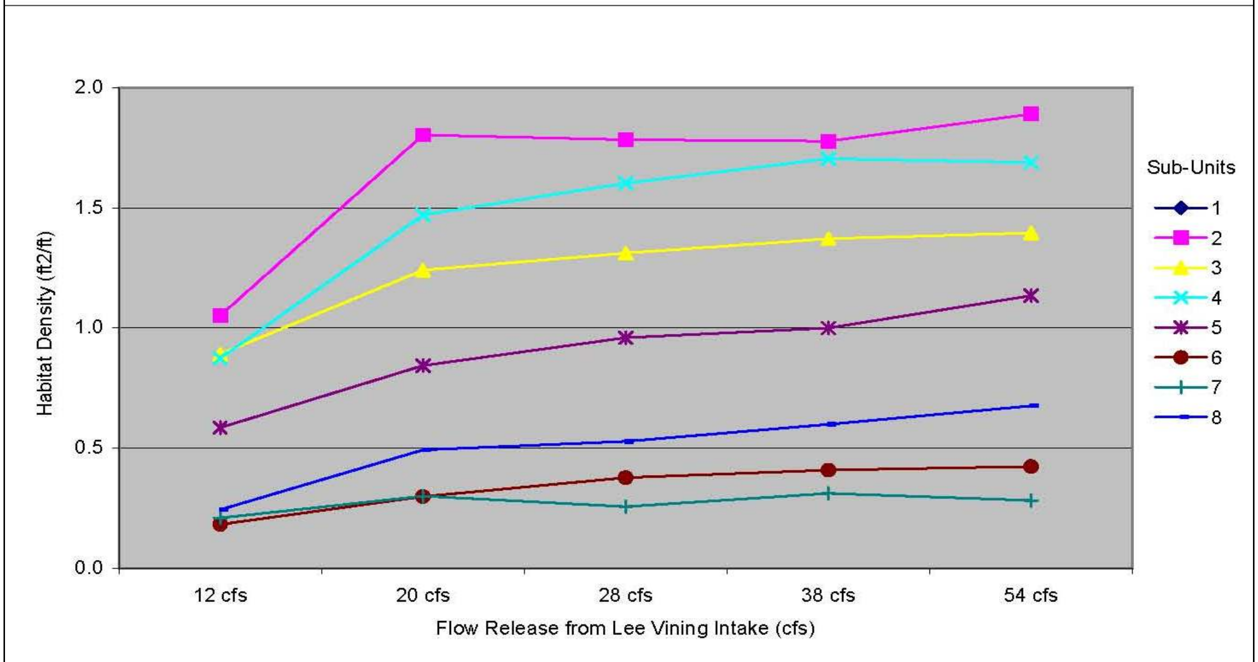


Figure 29. Individual BMI habitat rating curves for the Lee Vining Creek reach mapped in April and May 2009.

The mainstem BMI mapping reach was relative uniform, dominated by a few long riffles, interrupted by short pool or pool-run units. Individual habitat rating curves were thus less variable than were observed for Rush Creek (Figure 23a). The first sub-unit (584 ft long) dominated the overall habitat area and dictated the trend observed in the composite curve. The remaining individual curves varied very little in their response to change in discharge, with the exception that most individual curves had the largest increase in habitat area from 12 to 20 cfs (Figure 23a).

3.11 Rush Creek Channel Widths

Mean wetted widths were computed during four test flows at 15 riffle transects marked by pin-flags within the Upper Rush Reach section and from 17 riffle transects within the Bottomlands Reach (Table 8). Total values for all 32 transects combined were also presented (Table 8). The losses that occurred to mean riffle widths when flows were decreased from the highest to the lowest test flows were computed to the nearest 0.1 ft. and also as the percent loss in mean riffle width at each flow; where: % loss in Mean Wetted Width = Loss in mean width (ft) at each flow, divided by the mean width at the highest flow x 100 (Table 8).

Width-to-flow relationships were very similar at both reaches on Rush Creek where riffle widths were measured. Mean riffle widths steadily decreased as streamflows decreased. At Upper Rush, the maximum loss was 17.7% at the lowest test flow compared to the highest. At the Bottomlands, the maximum loss was 16.2% (Table 8).

Table 8. Mean wetted widths on four test flows at 32 cross sections during the Rush Creek IFS, August 2008.

15 Cross sections in Upper Rush Creek				
	90 CFS TEST FLOW	60 CFS TEST FLOW	30 CFS TEST FLOW	15 CFS TEST FLOW
Mean Width (ft)	31.6	30.2	28.7	26.0
Loss in Mean Width (ft)	0	1.4	2.9	5.6
Loss in Mean Width (%)	0	4.4%	9.2%	17.7%
17 Cross sections in Lower Rush Creek				
	90 CFS TEST FLOW	60 CFS TEST FLOW	30 CFS TEST FLOW	15 CFS TEST FLOW
Mean Width (ft)	32.8	31.6	29.5	27.5
Loss in Mean Width (ft)	0	1.2	3.3	5.3
Loss in Mean Width (%)	0	3.7%	10.1%	16.2%
All 32 Cross Sections Combined in Rush Creek				
	90 CFS TEST FLOW	60 CFS TEST FLOW	30 CFS TEST FLOW	15 CFS TEST FLOW
Mean Width (ft)	32.2	30.9	29.1	26.8
Loss in Mean Width (ft)	0	1.3	3.1	5.4
Loss in Mean Width (%)	0	4.0%	9.6%	16.8%

The mean wetted width of the riffles that were evaluated on Rush Creek decreased by approximately 17%, when the widths that were present at the lowest test flow were compared to those present at the highest flow (Table 8). However, to better illustrate the effect of reduced flows on the wetted widths of riffles below the Narrows, Figure 30 shows the percent loss of these widths at four measured streamflows at the Bottomlands Reach (Table 8).

The flow/width-loss relationships plotted on Figure 30 can be used to estimate the percent loss in wetted width that would occur to riffles below the Narrows at any measured streamflow from 14.1 to 77.3 cfs. Within a flow range of 19 to 23 cfs, which represents a good winter baseflow for adult brown trout (see Figure 8), the mean wetted width of riffles would only be reduced by approximately 12% to 13% compared to the width present at 77.3 cfs (refer to where the 19 and 23 cfs vertical lines intercept the flow/width-loss curve on Figure 30). This is a relatively small loss in potential fry and juvenile trout habitat (or even potential BMI habitat or trout spawning habitat), when compared to an almost doubling of adult trout holding habitat that occurred when baseflows were reduced from 77.3 to 23 cfs at the reaches below the Narrows (Figure 8).

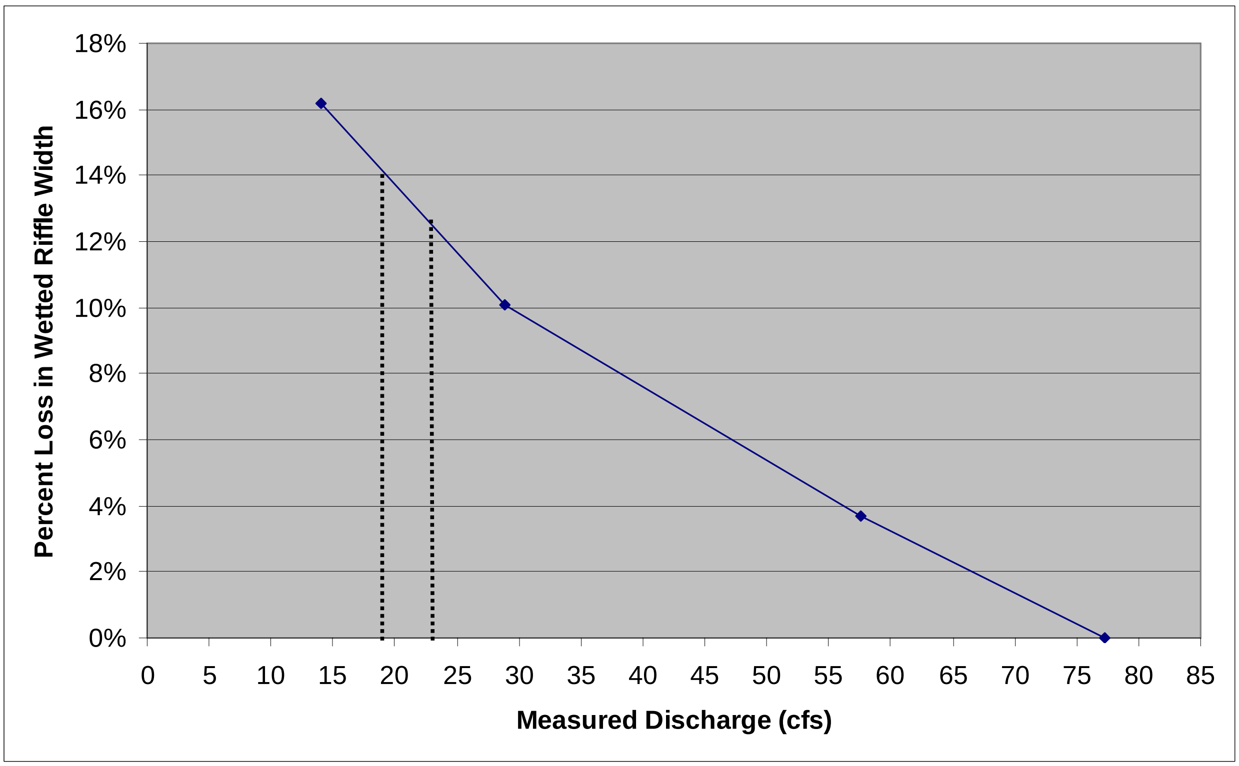


Figure 30. Percent loss in wetted riffle width versus measured discharge at 17 pin-flagged riffle cross sections in Rush Creek downstream of the Narrows, August 2008.

3.12 Lee Vining Creek Channel Widths

Wetted widths were measured at 52 pin-flagged transects within three reaches on Lee Vining Creek (Table 9). The Upper Reach was located within the old and new electrofishing sections, upstream of the County Road Ford. This was a relatively confined channel reach, with a stream bottom dominated by boulders and large cobble. Not surprisingly, there was little change (5.1%) in mean wetted riffle width between the highest and lowest test flows (Table 9).

The Middle Reach on Lee Vining Creek was composed of riffle units located just above and below the County Road Ford. There were numerous channel splits and braids within this reach. Channel bottom substrate was primarily cobble, with some gravel and other smaller materials. Of all the reaches that were evaluated on both streams, the Middle Lee Vining Reach exhibited the largest decrease in mean channel width (23.3%) between the highest and lowest test flows (Table 9).

The Lower Lee Vining Reach was a few hundred feet upstream of the Mono Lake delta, and was entirely within the lowest IFS pool mapping reach. Here, the stream was within a single channel, with small cobble and gravel making up the majority of the stream bottom substrate. The loss in mean wetted width that occurred between the highest and lowest test flows was 12.9%.

The loss in mean wetted width between the highest and lowest test flows for all 52 cross sections combined on Lee Vining Creek was 12.9% (Table 9). This value was slightly lower than the combined value for all 32 cross sections on Rush Creek, which was 16.8% (Table 8).

Table 9. Mean wetted widths on five test flows at 52 cross sections during the Lee Vining Creek IFS, April 2009.

22 Cross Sections in Upper Lee Vining Creek					
	54 CFS TEST FLOW	37 CFS TEST FLOW	28 CFS TEST FLOW	20 CFS TEST FLOW	12 CFS TEST FLOW
Mean Width (ft)	23.7	23.5	23.4	23.1	22.5
Loss in Mean Width (ft)	0	0.2	0.3	0.6	1.2
Loss in Mean Width (%)	0	0.8%	1.3%	2.5%	5.1%
16 Cross Sections in Mid Lee Vining Creek					
	54 CFS TEST FLOW	37 CFS TEST FLOW	28 CFS TEST FLOW	20 CFS TEST FLOW	12 CFS TEST FLOW
Mean Width (ft)	23.1	22.7	19.5	18.7	17.7
Loss in Mean Width (ft)	0	0.4	3.6	4.4	5.4
Loss in Mean Width (%)	0	1.7%	15.6%	19.0%	23.3%
14 Cross Sections in Lower Lee Vining Creek					
	54 CFS TEST FLOW	37 CFS TEST FLOW	28 CFS TEST FLOW	20 CFS TEST FLOW	12 CFS TEST FLOW
Mean Width (ft)	25.6	24.7	24.2	23.5	22.0
Loss in Mean Width (ft)	0	0.9	1.4	2.1	3.6
Loss in Mean Width (%)	0	3.5%	5.5%	8.2%	14.1%
All 52 Cross Sections Combined in Lee Vining Creek					
	54 CFS TEST FLOW	37 CFS TEST FLOW	28 CFS TEST FLOW	20 CFS TEST FLOW	12 CFS TEST FLOW
Mean Width (ft)	24.0	23.6	22.4	21.9	20.9
Loss in Mean Width (ft)	0	0.4	1.6	2.1	3.1
Loss in Mean Width (%)	0	1.7%	6.7%	8.8%	12.9%

4 DISCUSSION OF INSTREAM FLOW NEEDS

4.1 Rush Creek – Winter Holding Habitat

Within the Bottomlands and County Road reaches, the amount of winter holding habitat for adult brown trout steadily declined from the lowest (14.1 cfs) to the highest (77.3 cfs) streamflows (Table 6). It was not possible to determine whether more holding habitat might have been present at flows less than 14.1 cfs or between 14.1 and 28.8 cfs by examining the flow-habitat relationship curves for these two reaches (Figure 8). Fortunately, flow-habitat relationships for measured flows of 12.1 and 19.2 cfs were mapped within the Old Lower Mainstem reach (the two highest flows evaluated at this reach) and flows of 12.3 and 22.6 cfs were mapped in the 10-Channel reach (the two lowest flows here). Within these reaches, the most area of adult trout holding habitat was mapped at flows of 19.2 and 22.6 cfs, respectively. Areas of winter holding habitat steadily declined at all of the reaches below the Narrows when streamflows were above 22.6 cfs (Figure 8). In the Upper Rush Creek mapping reach winter holding habitat was highest at flows of 30 cfs (Figure 6). However, there was little winter holding habitat in Upper Rush Creek at any flow tested and the difference between 15 cfs and 30 cfs was relatively small.

These analyses suggest that a winter baseflow (as measured at the study reaches) ranging from approximately 19 to 23 cfs would provide the most area of adult trout holding habitat in Rush Creek downstream of the Narrows and flows of about 30 cfs would provide the most area in the Upper Rush Creek reach. To achieve this range of measured flows (19-23 cfs) in reaches downstream of the Narrows, flows released by DWP from the MGORD must be in the 28 to 32 cfs range (based on August 2008 synoptic discharge measurements). These habitat-needs analyses assumed a combined accretion of approximately 5 cfs from Parker and Walker Creek as a typical winter baseflow, if actual baseflows were slightly higher or lower, then minor adjustments could be made to DWP's release at the MGORD. Finally, these habitat-needs analyses made no assumption that the flow losses experienced at the time of the IFS mapping (August 2008) were reflective of losses or gains that may occur in Rush Creek during the winter period. Winter flow losses will be analyzed with available data in the Synthesis Report.

4.2 Rush Creek – Foraging Habitat

Winter baseflows that provide the most winter holding habitat described above will not be the best flows during the summer because during periods of hot weather these relatively low flows would allow for excessive warming of the water and would limit production of benthic macroinvertebrates by reducing riffle habitat area. Condition and abundance of brown trout in Rush Creek below Grant Reservoir have been shown to be influenced by flows, water temperatures, and water levels in Grant Reservoir (Shepard et al. 2009). A temperature model that predicts daily water temperatures based primarily on climate and flow data will be used to evaluate how different flows affect water temperatures throughout Rush Creek below Grant Reservoir. This temperature model will be integrated with these IFS analyses of trout and BMI habitat availability to assess different flow regimes as part of the Synthesis Report. When prescribing higher spring and summer baseflows, which will most likely provide cooler water temperatures and probably stimulate higher rates of BMI (secondary) production, consideration will also be given to the effects of these increased flows on the concurrent losses to adult trout holding habitat. For example, increasing stream discharge rates from a winter baseflow of 19 to 23 cfs to, say, 45 cfs would still leave 77 to 88% of the adult holding habitat present at the 23 cfs winter flow (Figure 5); however, increasing flows to 75 cfs would reduce adult holding habitat to only 53 to 56% of the amount present during a prescribed winter baseflow of 19 to 23 cfs.

4.3 Lee Vining Creek – Winter Holding Habitat

Although winter holding habitats in Lee Vining Creek were most available at the lowest test flow of 12 cfs, we have concerns that this low a discharge released during winter months may result in icing that could harm over-wintering trout. Cunjak (1996) demonstrated that in colder areas during low winter flows, extensive icing reduced the availability of low velocity habitats for trout. While we do not have specific information regarding the formation of frazil and anchor ice in Lee Vining Creek, several characteristics of the Lee Vining channel are consistent with factors that may contribute to ice formations. These factors as presented by several researchers include: a shallow channel with large/coarse substrate, transitional reaches from steeper to milder channel slopes, and channel reaches located immediately downstream of more turbulent reaches (Prowse 2001; Bradford and Heinonen 2008; NOAA 2009).

A re-examination of the composite habitat-flow relationship curve suggests that a flow release of 18-20 cfs would provide approximately the same amount of holding habitat as a 28 cfs release (Figure 31). The rationale for not selecting 28 cfs as a potential winter baseflow recommendation for Lee Vining Creek in the upcoming Synthesis Report is two-fold. First, the increase in holding habitat between 20 and 28 cfs on the composite curve was mostly influenced by Unit #13, the large pool located near the Mono Lake delta (Figure 14). While this pool currently provides habitat, it is located at an elevation above mean sea level (6,386 ft) that will be submerged as Mono Lake rises towards its targeted recovery elevation of 6,392 ft. Secondly, the increase in test flow release between 20 and 28 cfs resulted in a 42% decrease of winter holding habitat in Class-5 Pool #1; whereas the holding habitat loss in this high-quality pool between 12 and 20 cfs was less than 6% (Figure 32).

The pool/habitat typing survey conducted along the lower 10,000-foot reach of Lee Vining Creek, in combination with the IFS habitat mapping, revealed the relative paucity of pools and "good" pool habitat within Lee Vining Creek. Within the 10,000-foot habitat-typing survey reach a total of 97 habitat units were identified, of which 47 were high-gradient riffles. The total length of high-gradient riffles was 7,617 ft (about 76% of the reach). Twenty-five individual pool units accounted for only 1,087 ft of the 10,000-foot survey reach and 25 run/glide units accounted for another 1,216 ft. The relative lack of pools in lower (below Highway 395) Lee Vining Creek is most likely a function of channel gradient and slope and relative lack of large wood; however, continued evolution of pools and deep runs is dependant on further recovery of the riparian vegetation in conjunction with future SRF releases. We also compared the densities (ft^2/100 ft of channel) of winter holding habitat in Lee Vining Creek below the County Road to densities within the Rush Creek County Road mapping section. This comparison showed that the relative amounts of winter holding habitat in Rush Creek were four-to-five times greater than in Lee Vining Creek at all comparable flows (Figure 33).

Lower Lee Vining Creek has a much lower frequency of pools than lower Rush Creek. This low availability of pool habitats in Lee Vining Creek limits this stream's ability to support larger trout, regardless of baseflow levels. The relatively high channel gradient, lack of a well-developed riparian community, and relatively large channel substrate are probably contributing to the slow pace at which pool habitats are developing in this stream. Until more high-quality pools become established in this channel, adjustments to winter baseflows may have only a moderate influence on production of larger brown trout.

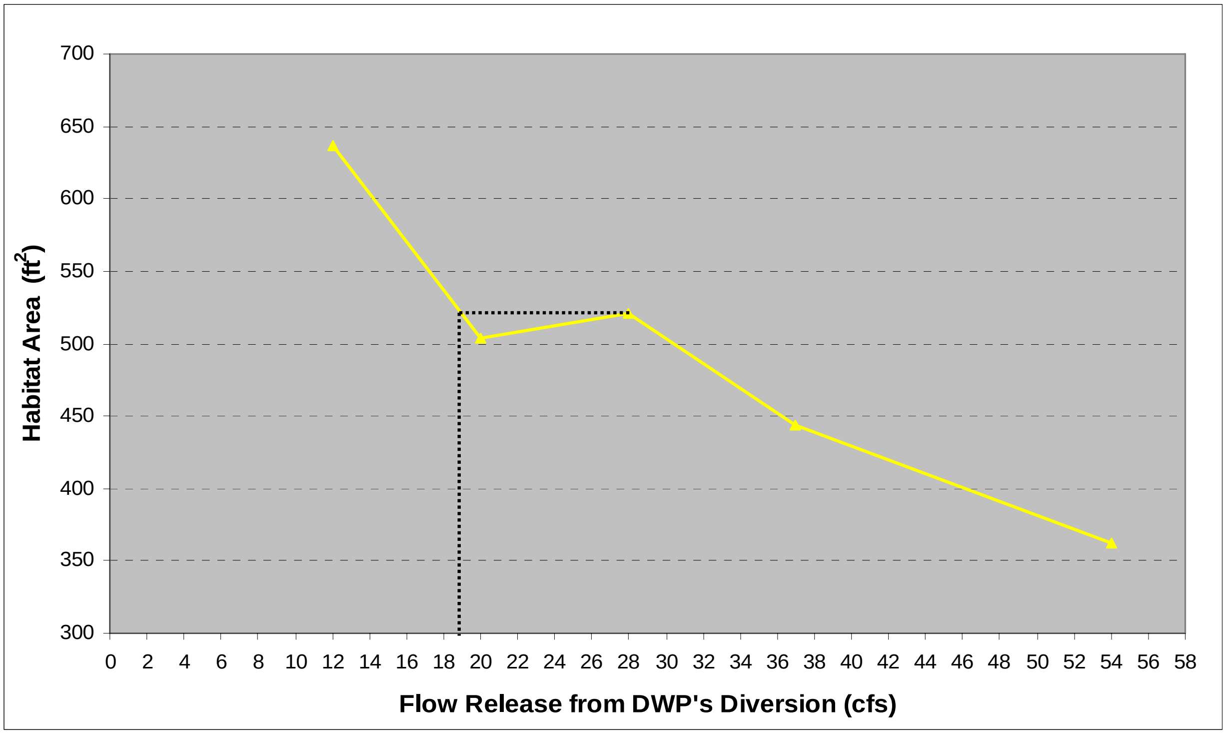


Figure 31. Composite habitat-flow relationship curve of adult brown trout winter holding habitat for Lee Vining Creek, April 2009. Y-axis has been changed to start at 300 ft^2 instead of 0 to exaggerate the slope of the curve.

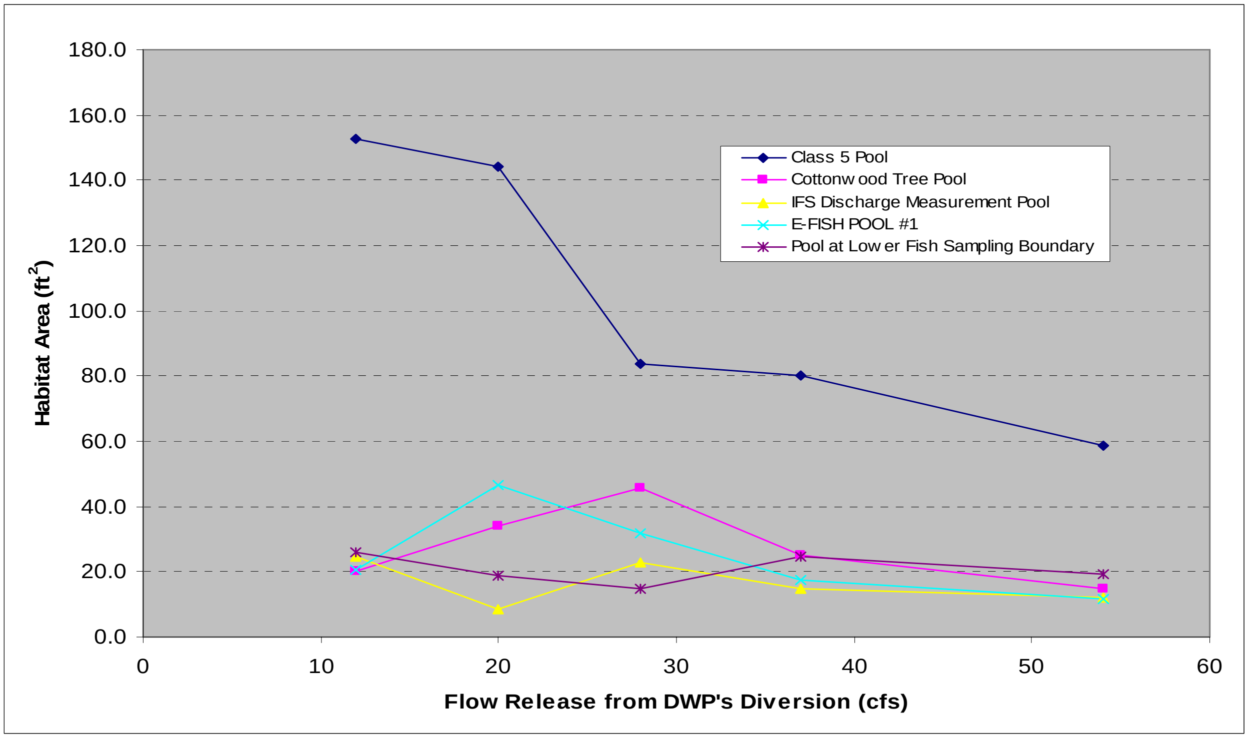


Figure 32. Individual habitat-flow relationship curves of adult brown trout winter holding habitat for all five pool units located upstream of the County Road on Lee Vining Creek, April 2009.

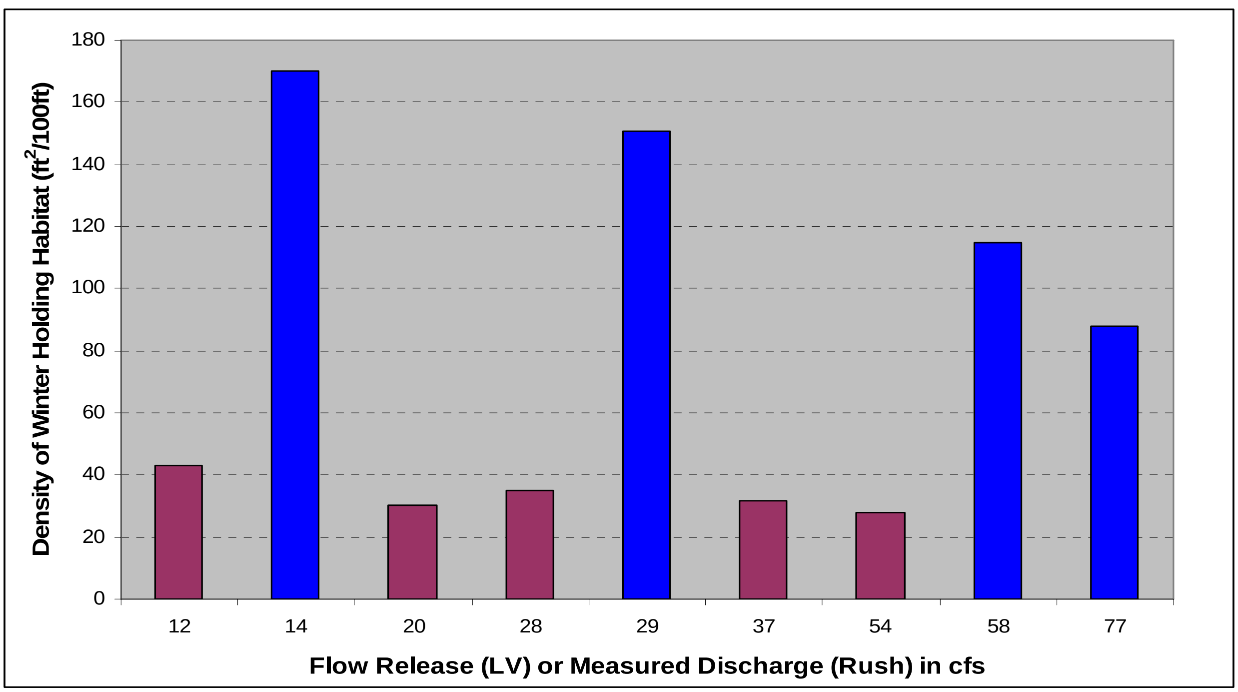


Figure 33. Comparison of winter holding habitat densities in the lower-most mapping reaches of Lee Vining Creek (purple) and Rush Creek (blue).

4.4 Lee Vining Creek – Foraging Habitat

In Lee Vining Creek, the total area of foraging habitat was highest at the lowest test flow release of 12 cfs (Figure 15). The total area of foraging habitat dropped by approximately 7% between the 12 and 20 cfs test flows; however the amount of foraging habitat in pocket pools increased by nearly 75% as flows rose from 12 to 20 cfs (Figures 15 and 16). As previously stated, the pool/habitat typing survey results revealed that 76% of the 10,000-foot surveyed reach was comprised of high-gradient riffles. We also noted during habitat mapping that the frequency of pocket pools dropped as channel slope and confinement decreased in a downstream direction. Conversely, the amount (by channel length) of high-gradient riffles was higher in Lee Vining Creek upstream of our mapping reach. The uppermost 2,000' of the pool/habitat typing reach located upstream of our mapping reach was comprised of 95% riffles and 137 pocket pools were enumerated in this upper reach. Because of the dominance of riffle habitats in Lee Vining Creek, we believe that development of flow recommendations in the Synthesis Report to address foraging habitat should consider pocket pools as a priority over pool habitats when trade-offs are evaluated.

We again emphasize the dynamic nature of the stream channels in both lower Rush and Lee Vining creeks. As these channels and their associated riparian zones continue to develop over time, habitat-to-flow relationships will undoubtedly change. We recommend that these relationships be re-evaluated after another 10 years, or if channel monitoring indicates either channel cross-sectional areas or pool habitat frequencies have appreciably changed.

4.5 Rush Creek – BMI Habitat Summary

Water temperature will be a critical variable to integrate with the BMI hydraulic habitat area in the Synthesis Report. Strictly in terms of hydraulic criteria and substrate suitability (i.e., the three BMI mapping criteria), the intermediate and higher flow ranges observed on Rush Creek, 45, 60, and 90 cfs, generally offered the highest BMI habitat abundance (Figure 21). However, the two reaches with the highest habitat density (Figure 21) – Upper Rush and the Bottomlands – actually decreased slightly from 45 to 90 cfs. The highest increase in habitat area was observed from 30 to 45 cfs. The individual habitat rating curves from Upper Rush and the Bottomlands reaches (Figure 23) indicate a small subset of the total habitat units mapped may bias the composite habitat area and resulting rating curves. However, given that these units may represent broader reach-wide conditions, our analysis could not discount those sub-units. The field mapping of inundated channel area also indicated a steeper increase in inundated area as flow increased from 45 to 60 cfs (Figure 24). This feature of the data reflected an important threshold observed in the field, in which medial and lateral gravel bars began to inundate, small braided channels began to flow, and the wetted channel margins continued their migration up the edge of shallow banks. The 45 cfs flow release initiated this trend, which continued through the 90 cfs release. Overall, flow releases from the MGORD of 45 cfs and above provided abundant BMI habitat area in our mapping reaches. As flows increased above 45 cfs, the inundated channel area began to exceed thresholds for inundating gravel/cobble bar features, incorporating more exposed substrate area into the wetted channel. Our mapping data do not indicate if BMI habitat peaks and then begins to decline beyond 90 cfs MGORD flow releases.

4.6 Lee Vining Creek – BMI Habitat Summary

Lee Vining Creek had abundant BMI habitat that met our criteria. This resulted from the predominance of medium and high gradient riffles, coarse bed substrates, and general low percentage of fine sediment and embeddedness within our mapping reach. As a general indication of BMI habitat abundance, the peak BMI habitat area at 54 cfs (19,395 ft^2) represented 58% of the total wetted channel mapped at 54 cfs. Lee Vining Creek also has year-round cold water temperatures that suit BMI productivity. However, because of the relatively high channel confinement observed over the range of test flows, water depths and velocities increased with each increase in flow more so than did wetted channel area. Consequently hydraulic characteristics of the five test flow releases were different. The 12 and 20 cfs test flow releases had abundant shallow and/or slow areas along stream margins and in pockets within mid-channel areas (Figure 34). Much of these areas disappeared at the 54 cfs flow release. At 54 cfs, flow became relatively homogenous through large sections of the reach, with strong currents and sparse velocity breaks. The 54 cfs release also appeared close to a threshold where large sections of channel would exceed the 1.5 ft depth criterion. Small pockets of channel within the larger BMI habitat polygons that were mapped as "out" because they exceeded the depth criterion became apparent at 38 cfs and peaked at 54 cfs. This trend likely continued beyond 54 cfs, and thus BMI habitat abundance may reach a peak within the low-flow channel at or near 54 cfs. The two intermediate flows of 28 and 38 cfs provided abundant BMI habitat area, had measurable flow through the A4 Channel, but still preserved a high diversity of shallow and slow water along the margins of the mainstem channel.

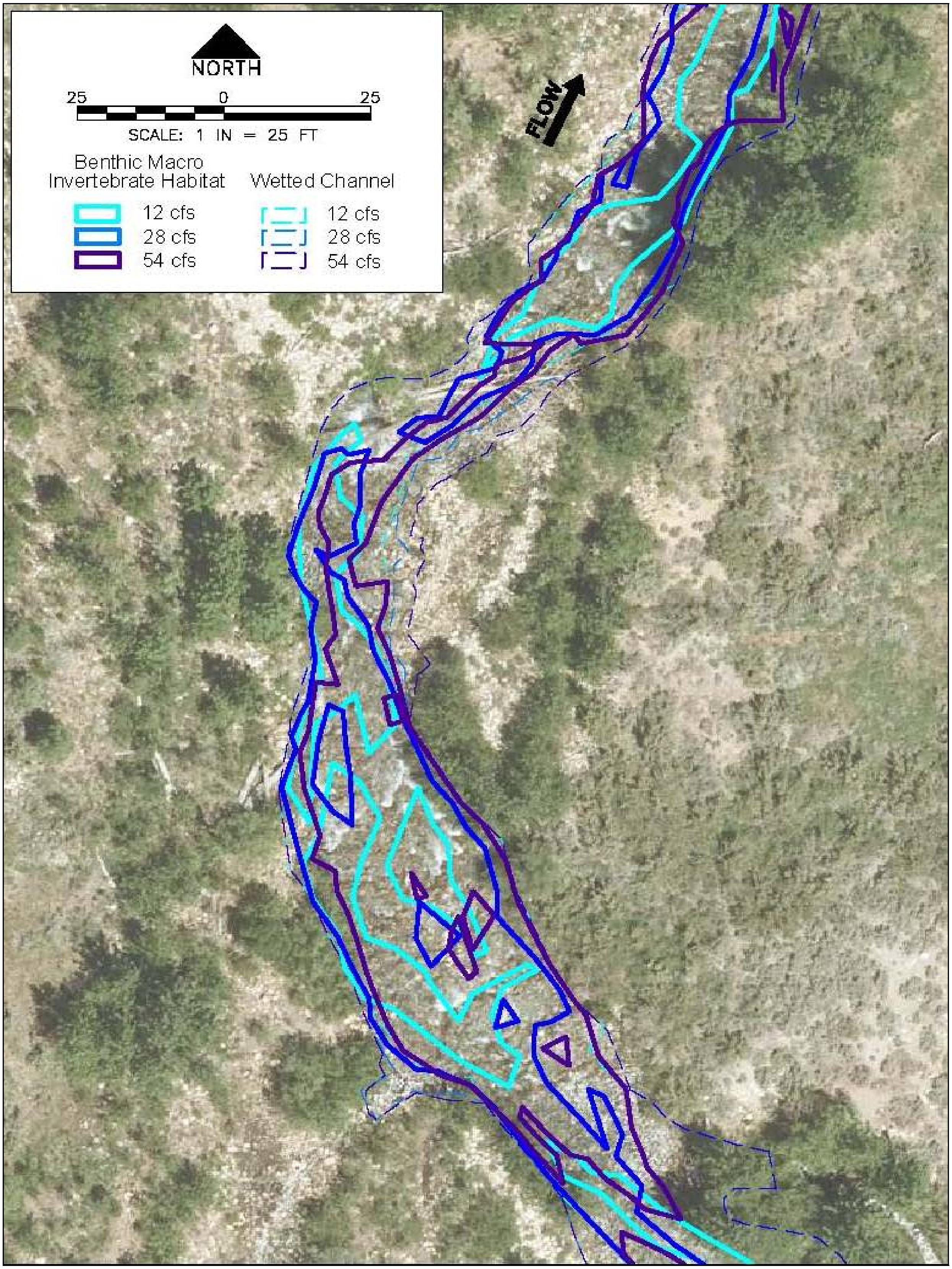


Figure 34. Example habitat map showing three of the five BMI polygons mapped on Lee Vining Creek.

5 LITERATURE CITED

Alfredsen, K. and E. Tesaker. 2002. Winter habitat assessment strategies and incorporation of winter habitat in the Norwegian habitat assessment tools. Hydrological Processes 16: 927-936.

Annear, T., Chisholm, I., Beecher, H., Locke, A., Aarestad, P., Coomer, C., Estes, C., Hunt, J., Jacobson, R., Jobsis, G., Kauffman, J., Marshall, J., Mayes, K., Smith, G., Wentworth, R., and Stalnaker, C. 2004. Instream flows for riverine resource stewardship. Revised edition. Instream Flow Council, Cheyenne, Wyoming.

Bachman, R. A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Transactions of the American Fisheries Society 113(1): 1-32.

Beisel, J.N., P. Useeglio-Polatera, S. Thomas, and J.C. Moreteau. 1998. Stream community structure in relation to spatial variation: the influence of mesohabitat characteristics. Hydrobiologia 389: 73-88.

Bjornn, T.C. and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. In W.R. Meehan (ed), Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Maryland.

Bradford, M.J. and J.S. Heinonen. 2008. Low flows, instream needs and fish ecology in small streams. Canadian Water Resources Journal 33 (2): 165-180.

Chamberlain, C.D., A.C. Martin, P.P. Petros. 2007. Trinity River biological monitoring of channel rehabilitation sites: A pre-construction baseline habitat evaluation. U. S.Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata Fisheries Technical Report TR 2007-07, Arcata, California.

CDFG. 1991. Instream flow requirements for brown trout- Rush Creek, Mono County, California. California Department of Fish and Game Steam Evaluation Report No. 91-2; Vol. 1.

CDFG. 1993. Instream flow requirements for brown trout- Lee Vining Creek, Mono County, California. California Department of Fish and Game Steam Evaluation Report No. 93-2; Vol. 1.

Corkum, L.D. 1989. Patterns of benthic invertebrate assemblages in rivers of Northwestern North America. Freshwater Biology 21: 191-205.

Cunjak, R. A., and G. Power. 1986. Winter habitat utilization by stream resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*). Canadian Journal of Fisheries and Aquatic Sciences 43: 1970-1981.

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences 53: 267-282.

Degani, G., G.N. Herbst, R. Ortal, H.J. Bromley, D. Levanon, Y. Netzer, N. Harari, and H. Glazman. 1993. Relationship between current velocity, depth, and the invertebrate community in a stable river system. Hydrobiologia 263: 163-172.

Doledec, S., N. Lamouroux, U. Fuchs, and S. Merigoux. 2007. Modelling the hydraulic preferences of benthic macroinvertebrates in small European streams. Freshwater Biology 52: 145-164.

Elliot, J.M. 1973. The food of brown and rainbow trout (Salmo trutta and S. Gairdneri) in relation to the abundance of drifting invertebrates in a mountain stream. Oecologia (Berlin) 12:329-347.

Elliott, J. M. and M. A. Hurley. 1999. A new energetics model for brown trout, *Salmo trutta*. Freshwater Biology 42:235-246.

Fjellheim, A. 1996. Distribution of benthic invertebrates in relation to stream flow characteristics in a Norwegian river. Regulated Rivers: Research and Management 12: 263-271.

Fonstad, M.A., J.P. Reichling, and J.W. Van de Grift. 2005. The transparent velocity head-rod for inexpensive and accurate measurement of stream velocities. Journal of Geoscience Education, 53(1): 44-52.

Galli, John. 1990. Thermal impacts associated with urbanization and storm water best management practices. Final Report for the Maryland Department of Transportation, Bethesda, MD.

Gard, M. 2009. Demonstration flow assessment and 2-D modeling: perspectives based on instream flow studies and evaluation of restoration projects. Fisheries 34 (7):320-329.

Gore, J. A., 1987. Development and application of macroinvertebrate instream flow models for regulated flow management. In J. F. Craig & J. B. Kemper (eds), Regulated Streams: Advances in Ecology. Plenum Press, New York: 99-115.

Gore, J. A. 1989. Chapter 10. Models for predicting benthic macroinvertebrate habitat suitability under regulated flows, pp. 253-265 in Gore, J.A. and G.E. Petts (eds.) Alternatives in Regulated River Management, CRC Press, Inc., Baco Raton, Florida 1989, 344 p.

Gore, J.A., and R.D. Judy Jr. 1981. Predictive models of benthic macroinvertebrate density for use in instream flow studies and regulated flow management. Canadian Journal of Fish and Aquatic Science 38: 1363-1370.

Gore, J.A., D.J. Crawford, and D.S. Addison. 1998. An analysis of artificial riffles and enhancement of benthic community diversity by Physical Habitat Simulation (Phabsim) and direct observation. Regulated Rivers: Research and Management 14: 69-77.

Gore, J.A., J.B. Layzer, and J. Mead. 2001. Macroinvertebrate instream flow studies after 20 years: a role in stream management and restoration. Regulated Rivers: Research and Management 17: 527-542.

Greenberg, L., P. Svendsen, and A. Harby. 1996. Availability of microhabitats and their use by brown trout (*Salmo trutta*) and grayling (*Thymallus thymallus*) in the River Vojman, Sweden. Regulated Rivers:Research and Management 12: 287-303.

Hartman, G. F. 1963. Observations on behavior of juvenile brown trout in a stream aquarium during winter and spring. J. Fish. Res. Board Can. 20(3):769-787.

Heggenes, J. 2002. Flexible summer habitat selection by wild, allopatric brown trout in lotic environments. Transactions of the American Fisheries Society 131:287-298.

Hunter, C. J. 1991. Better Trout Habitat: A guide to stream restoration and management. Island Press, Washington DC/Covelo CA.

Hunter, C., B. Shepard, D. Mierau, K. Knudson, and R. Taylor. 2000. Fisheries Monitoring Report for Rush, Lee Vining, Parker and Walker Creeks 1999. Annual Report prepared for Los Angeles Department of Water and Power. 32 p.

Hunter, C., B. Shepard, K. Knudson, R. Taylor. 2001. Fisheries Monitoring Report for Rush, Lee Vining, Parker and Walker Creeks 2000. Annual Report prepared for LADWP. 32 p.

Hunter, C., B. Shepard, K. Knudson, R. Taylor, M. Sloat and A. Knoche. 2002. Fisheries Monitoring Report for Rush, Lee Vining, Parker and Walker Creeks 2001. Annual Report prepared for LADWP. 42 p.

Hunter, C., B. Shepard, K. Knudson, R. Taylor and M. Sloat. 2003. Fisheries Monitoring Report for Rush, Lee Vining, Parker and Walker Creeks 2002. Annual Report prepared for LADWP. 43 p.

Hunter, C., B. Shepard, K. Knudson, R. Taylor and M. Sloat. 2004. Fisheries Monitoring Report for Rush, Lee Vining, Parker and Walker Creeks 2003. Annual Report prepared for LADWP. 62 p.

Hunter, C., R. Taylor, K. Knudson, B. Shepard, and M. Sloat. 2005. Fisheries Monitoring Report for Rush, Lee Vining, Parker and Walker Creeks 2004. Annual Report prepared for LADWP. 54 p.

Hunter, C., R. Taylor, K. Knudson and B. Shepard. 2006. Fisheries Monitoring Report for Rush, Lee Vining, Parker and Walker Creeks 2005. Annual Report prepared for LADWP. 64 p.

Hunter, C., R. Taylor, K. Knudson and B. Shepard. 2007. Fisheries Monitoring Report for Rush, Lee Vining, Parker and Walker Creeks 2006. Annual Report prepared for LADWP. 74 p.

Hunter, C., R. Taylor, K. Knudson and B. Shepard. 2008. Fisheries Monitoring Report for Rush, Lee Vining, Parker and Walker Creeks 2007. Annual Report prepared for LADWP. 49 p.

Hunter, C., R. Taylor, K. Knudson and B. Shepard. 2009. Fisheries Monitoring Report for Rush, Lee Vining, Parker and Walker Creeks 2008. Annual Report prepared for LADWP. 74 p.

Hynes, H.B.N. 1970. The Ecology of running waters. University of Toronto Press.

Jowett, I.G. 2003. Hydraulic constraints on habitat suitability for benthic invertebrates in gravel-bed rivers. River Research and Applications 19: 495-507.

Jowett, I.G., J. Richardson, B.J.F. Biggs, C.W. Hickey, and J.M. Quinn. 1991. Microhabitat preferences of benthic invertebrates and the development of generalized *Deleatidium* spp. habitat suitability curves, applied to four New Zealand rivers. New Zealand Journal of Marine and Freshwater Research, 25: 187-199.

Jowett, I.G. and A.J.H. Davey. 2007. A comparison of composite habitat suitability indices and generalized additive models of invertebrate abundance and fish presence-habitat availability. Transactions of the American Fisheries Society 136: 428-444.

Leathe, S.A., and F.A. Nelson. 1989. A literature evaluation of Montana's wetted perimeter inflection point method for deriving instream flow recommendations. Montana Department of Fish, Wildlife and Parks, Helena, Mont, February, 1989.

McBain and Trush. 2004a. Monitoring results and analyses for runoff year 2004: Lee Vining, Rush, Walker, and Parker Creeks. Annual Report prepared for Los Angeles Department of Water and Power, Los Angeles, California.

McBain and Trush, Inc. 2004b. Estimating salmonid habitat availability in the Oak Grove Fork using Expert Habitat Mapping: Summary of methods and results. Report to Clackamas Instream Flow/ Geomorphology Subgroup and Portland General Electric. 27 p.

McBain and Trush. 2005. Monitoring results and analyses for runoff year 2005: Lee Vining, Rush, Walker, and Parker Creeks. Annual Report prepared for Los Angeles Department of Water and Power, Los Angeles, California.

McBain and Trush. 2009. Monitoring results and analyses for runoff year 2009: Lee Vining, Rush, Walker, and Parker Creeks. Annual Report prepared for Los Angeles Department of Water and Power, Los Angeles, California.

McFadden, J.T., and E.L. Cooper. 1964. An ecological comparison of six populations of brown trout (Salmo trutta). Transactions of the American Fisheries Society 91:53-62.

Merigoux, S. and S. Doledec. 2004. Hydraulic requirements of stream communities: a case study on invertebrates. Freshwater Biology 49: 600-613.

Merigoux, S., N. Lamouroux, J.M. Olivier, and S. Doledec. 2009. Invertebrate hydraulic preferences and predicted impacts of changes in discharge in a large river. Freshwater Biology 54: 1343-1356.

Mierau, D.W. 1996. Invertebrate colonization and downstream drift: Structure and formation of the benthic invertebrate community in lower Hat Creek, CA. Master's Thesis. Humboldt State University, Arcata, CA.

Murphy, M.L. and W.R. Meehan. Stream Ecosystems. 1991. In W.R. Meehan (ed), Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Maryland.

Needham, P.R. 1969. Trout streams – revised edition. Winchester Press, New York, NY. 241 p.

NOAA. 2009. River ice and river ice processes. NOAA Weather Service Forecast Office, Billings, MT. http://www.wrh.noaa.gov/tfx/hydro/IJAD/RiverIceTypes.php?wfo=byz

Orth, D.J., and E. Maughan. 1983. Microhabitat preferences of benthic fauna in a woodland stream. Hydrobiologia 106: 157-168.

Orth D.J. 1987. Ecological considerations in the development and application of instream flow-habitat models. Regulated Rivers: Research and Management 1: 171–181

Platts, W. S., Megahan, W. F., and G. W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. USDA Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report INT-138. Ogden, Utah.

Prowse, T.D. 2001. River-ice ecology I: Hydrologic, geomorphic, and water quality aspects. ACE Journal of Cold Regions Engineering 15 (1): 1-16.

Raleigh, R. F., L. D. Zuckerman, and P. C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: brown trout, revised. U.S. Fish and Wildlife Service, Biological Report 82(10.124). 65 pp. [First printed as: FWS/OBS-82/10.71, September 1984-J.

Reimers, N. 1963. Body condition, water temperature, and over-winter survival of hatchery-reared trout in Convict Creek, California. Transactions of the American Fisheries Society 92: 39-46.

Saunders, W.C. and K.D. Fausch. 2007. Improved grazing management increases terrestrial invertebrate inputs that feed trout in Wyoming rangeland streams. Transactions of the American Fisheries Society 136: 1216-1230.

Shepard, B., R. Taylor, K. Knudson, and C. Hunter. 2009. Effects of flow, reservoir storage, and water temperatures on trout in lower Rush and Lee Vining creeks, Mono County, California. Report to Los Angeles Department of Water Power, Los Angeles, California.

Statzner B. and B. Higler. 1986. Stream hydraulics as a major determinant of benthic invertebrate zonation patterns. Freshwater Biology. 16, 127-139.

Statzner, B., Gore, J.A., and Resh, V.H. 1988. Hydraulic stream ecology: patterns and potentials. Journal of the North American Benthological Society 7.

Stillwater Sciences. 2006. Aquatic habitats and instream flows at the Carmen-smith hydro-electric project, upper McKenzie River basin, Oregon. Final report, prepared for the Eugene Water and Electric Board. 71 p.

Talbot C. 1993. Some aspects of the biology of feeding and growth in fish. Symposium on 'Fish and Nutrition'. Proceedings of the Nutrition Society (1993), 52, 403-416.

Trush, W. J. 1979. M.S. Zoology (1979). The Effects of Area and Surface Complexity on the Structure and Formation of Stream Benthic Communities. Masters Thesis. Center for Environmental Studies, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Ward J.V. and J.A. Stanford. 1979. The Ecology of Regulated Streams. Plenum Press, New York.

Wills, T.C., E.A. Baker, A.J. Nuhfer, and T.G. Zorn. 2006. Response of the benthic macroinvertebrate community in a Northern Michigan stream to reduced summer streamflows. River Research and Applications 22: 819-836.