FINAL REPORT ◦ SEPTEMBER 2017

Lower Tuolumne River Instream Flow Study—Evaluation of Effective Usable Habitat Area for over-summering *O. mykiss*

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Cover photo:
Habitat suitability criteria site-specific survey on the lower Tuolumne River, May 2012.

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1 BACKGROUND

Per Federal Energy Regulatory Commission (Commission) Order issued on July 16, 2009, the Turlock Irrigation District and Modesto Irrigation District (collectively: Districts) in consultation with resource agencies, were required "to develop and implement an instream flow incremental methodology (IFIM) study to determine instream flows necessary to maximize Chinook salmon (*Oncorhynchus tshawytscha*) and Central Valley steelhead (*O. mykiss*) production and survival throughout various life stages. The results of the physical habitat simulation (PHABSIM) flow model under the IFIM framework would assist in identifying the amount of available habitat (weighted usable area) for the species under various flow conditions." In addition, the Order required the Districts to develop a water temperature model in conjunction with the instream flow study "to determine the downstream extent of thermally suitable habitat to protect summer juvenile *Oncorhynchus mykiss* rearing under various flow conditions and to determine flows necessary to maintain water temperatures at or below 68 degrees Fahrenheit from La Grange Dam to Roberts Ferry Bridge."

On October 14, 2009, the Districts submitted to the Commission two study plans; the *Lower Tuolumne River Instream Flow Studies – Final Study Plan* ("IFIM Study Plan") (Stillwater Sciences 2009a) and the *Lower Tuolumne River Water Temperature Modeling – Final Study Plan* (Water Temperature Model Study Plan) (Stillwater Sciences 2009b). The IFIM Study Plan and the Water Temperature Model Study were modified and approved, pursuant to the Commission's May 12, 2010 Order.

In order to examine the broad flow ranges identified in the Commission's July 16, 2009 Order, the IFIM Study Plan separated the study into two separate investigations: (1) A conventional one-dimensional (1-D) PHABSIM model which examined in-channel habitat conditions affecting Chinook salmon (*O. tshawytscha*) and Central Valley steelhead (*O. mykiss*) at flows from approximately 100–1,000 cfs and (2) a 2-D hydraulic model of overbank areas, as well as adjacent in-channel locations, for flows of 1,000–5,000 cfs. The *Lower Tuolumne River Instream Flow Studies – Pulse Flow Study Report* (Stillwater Sciences 2012) covering the 2-D hydraulic model of overbank areas was filed with the Commission on June 18, 2012. The *Lower Tuolumne River Instream Flow Study – Final Report* (Stillwater Sciences 2013) covering 1-D PHABSIM modeling of in-channel conditions was filed with the Commission on April 26, 2013.

The Water Temperature Model Study Plan approved by the May 12, 2010 Commission Order was satisfied with the *Tuolumne River Water Temperature Modeling Study–Final Report* submitted on March 11, 2011 (Stillwater Sciences 2011). The 2011 report incorporated the HEC-5Q water temperature model that was developed for the Tuolumne River and other tributaries of the San Joaquin River with CALFED funding (RMA 2008). Subsequent to the filing of the 2011 water temperature study report, the Lower Tuolumne River Temperature Model (TID/MID 2017b) was developed during the Don Pedro Hydroelectric Project relicensing process. The 2013 model was developed specifically for the lower Tuolumne River using the HEC-RAS platform and features improved calibration performance and connectivity to reservoir operations not found in the HEC-5Q model.

As described in the IFIM Study Plan, this report fulfils the remaining requirements of the Commission's May 12, 2010 Order pertaining to the instream flow study and presents a summertime water temperature suitability component for fry, juvenile, and adult *O. mykiss* that integrates both hydraulic and thermal habitat considerations. The results from the Lower Tuolumne River Temperature Model (TID/MID 2017b) over a range of flows were combined with results from *Instream Flow Study* 1-D PHABSIM model results (Stillwater Sciences 2013) to examine the downstream extent of thermally suitable habitat. The Lower Tuolumne River Temperature Model (TID/MID 2017b) was used to assess flow and air temperature conditions necessary to maintain various water temperature thresholds (including 20°C [68°F]) at varying downstream locations, including Robert's Ferry Bridge (RM 39.5), as required by the Commission's July 2009 Order.

Review comments received from the U.S. Fish and Wildlife Service (USFWS) discussed in Appendix A requested the analysis be expanded to evaluate the applicable water temperature metric for *O. mykiss* contained in the USEPA (2003) *Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards*. In addition to the evaluation of the temperature thresholds described in the IFIM Study Plan this report also includes analysis of an 18°C (66.4°F) temperature metric calculated as the maximum of the 7-day average of the daily maximum (7DADM).

2 OBJECTIVES

The objective of this evaluation is to estimate the "effective" weighted usable area (eWUA) of select lower Tuolumne River habitat reaches for various life history stages of *O. mykiss* during the summer months (i.e., June-September). The evaluation of eWUA is an alternate depiction of the traditional weighted usable area (WUA) vs. flow relationship used in stream habitat analysis, which is traditionally based upon physical (i.e., depth, velocity, and/or substrate and cover) parameters (Bovee 1982). Depending on thermal conditions during summertime, the total usable area in a river reach for rearing *O. mykiss* (WUA multiplied by the length of the reach) at a given flow may be lower than depicted by the standard WUA vs. flow relationship if temperatures are unsuitable. The combined influences of hydraulic habitat suitability and thermal suitability for a given *O. mykiss* life stage (i.e., fry, juvenile, and adult) is quantified and described in this report as eWUA.

Flow in the lower Tuolumne River necessary to maintain specified downstream water temperatures can be greatly influenced by diurnal maximum air temperatures, especially during summer months (June–September). The current Lower Tuolumne River Temperature Model (TID/MID 2017b) is used to provide supplemental information on the effects of maximum air temperatures on modeled water temperatures and to provide the thermal conditions for use in analyzing eWUA.

3 METHODS

3.1 Temperature Evaluation Thresholds

The primary metric used in this analysis to assess thermal suitability for over-summering *O. mykiss* is the maximum weekly average temperature (MWAT). The MWAT is a commonly used measure of chronic (i.e., sub-lethal) exposure when considering the effect of temperature on salmonids (Carter 2005). In this analysis, a MWAT threshold of 20°C (68°F) was evaluated, as directed in the July 16, 2009 Order. Although the majority of historical (1996–2009) snorkel survey observations of *O. mykiss* in the lower Tuolumne River have occurred at temperatures of 20°C (68°F) or below (Ford and Kirihara 2010), *O. mykiss* have been routinely observed occupying Tuolumne River habitats at temperatures ranging from 11–25°C (52–77°C). Using wild juvenile *O. mykiss* collected from the Tuolumne River in the summer of 2014, a recently completed thermal performance study (Farrell et al. 2017) found a peak in the absolute aerobic scope[1] (AAS) vs. temperature curve at 21.2°C (70°F), higher than the 19°C (66°F) growth rate optimum identified by Myrick and Cech (2001). Because Farrell et al. (2017) also found that the AAS of the wild *O. mykiss* test fish remained within 5% of the peak AAS between 17.8°C (64°F) to 24.6°C (76°F), these site-specific empirical data with broader temperature thresholds were selected for evaluation of thermal suitability for *O. mykiss.* In the current study, the temperatures of 18°C (66.4°F), 20°C (68°F), 22°C (71.6°F), and 24°C (75.2°F) were evaluated over each of the summer months (June through September) when these temperatures can be exceeded in the lower Tuolumne River. Although not specified in either the July 16, 2009 or May 12, 2010 FERC orders, the evaluation of an 18°C (66.4°F) 7DADM is included as part of this analysis as requested by USFWS (Appendix A). The 18°C 7DADM threshold is described in USEPA (2003) guidance as a recommendation to protect salmonid migration and non-core[2] juvenile salmonid rearing.

3.2 Physical Habitat Modeling

The WUA results for this analysis were based on the PHABSIM model as described in the *Lower Tuolumne River Instream Flow Study–Final Report* (Stillwater Sciences 2013). The results from this model provide estimates of physical habitat for *O. mykiss* life stages over a range of constant flow simulations from 50–1,200 cfs, incorporating eight macrohabitat types and utilizing consensus-based habitat suitability criteria validated by site-specific field observations. The overall study reach for the analyses in the report extended from RM 51.9 downstream to near the city of Waterford, CA (RM 29). Finer sub-reach divisions were developed for the current study to allow for more detailed analysis of the usable habitat areas and related temperature conditions on a sub-reach basis. Using the PHABSIM model sub-reach divisions shown in Table **3-1**, Appendix B provides estimates of WUA (ft^2/1,000 ft) for each life history stage for each sub-reach over a discharge range of 50–1,200 cfs.

Table 3-1. Lower Tuolumne River PHABSIM sub-reach model boundaries.

Sub-reach model	Upstream RM	Downstream RM	Distance (feet)
1 (La Grange powerhouse to Basso Bridge)	51.9	46.9	26,400
2 (Basso Bridge. to Bobcat Flat)	46.9	43.1	46,464
3 (Bobcat Flat to Roberts Ferry Bridge)	43.1	39.5	64,944
4 (Roberts Ferry Bridge to Waterford)	39.5	29.1	120,384

Transect weighting within each sub-reach model reflects the percent occurrence (by length) of macrohabitats found within that sub-reach (Appendix C). To allow more precise sub-reach estimates to be combined with the spatially explicit HEC-RAS temperature model (HDR 2013) results, summation of the sub-reach-specific WUA (ft^2/1,000 ft) and channel length (ft) product

[1] Aerobic scope is defined here as the difference between resting and maximal oxygen consumption rates of swimming fish at various temperatures and relies upon an assumption that biochemical and physiological capacities of salmonids have evolved to optimize fitness related performance (e.g., growth, locomotion) within a particular temperature range.
[2] Non-core populations described in USEPA (2003) refer to "moderate to low density salmon and trout juvenile rearing during the period of summer maximum temperatures".

across 0.1 mile increments from RM 51.9 to RM 29.1 was used to estimate the total amount of usable habitat for each life stage within the study reach.

3.3 Water Temperature Model

The HEC-RAS version of the Lower Tuolumne River Temperature Model (TID/MID 2017b) was used to provide daily water temperature predictions at 0.5 mile increments from RM 51.9 downstream to near Waterford, CA (RM 29) under steady flow releases ranging from 100–1,200 cfs. These model runs incorporated historical meteorology data over a 42-year period of record dating from October 1970 through September 2012. Modeling results were also used to develop relationships between water temperature, air temperature and discharge at the downstream ends of the four sub-reach boundaries (RM 46.9, RM 43.1, RM 39.5, and RM 29.1).

3.4 Effective Useable Habitat Analysis

For each modeled constant flow release (100–1,200 cfs), the HEC-RAS water temperature model results (Section 3.3) were accumulated over the 42 year period of record at 0.5 mile intervals. Using linear interpolation, summary temperature statistics (MWATs and 7DADMs) were then determined for each summer month at 0.1 RM intervals along with how often the selected temperature thresholds were exceeded for each location and month within the period of record. To represent average conditions, the location at which the MWAT threshold was exceeded in half (21 of the 42) of the annual results was used in subsequent effective usable habitat estimates. In addition, the location at which the 18°C (66.4°F) 7DADM threshold was exceeded in 20%, 50%, and 80% of years was also calculated. Calculations of effective usable habitat were made using PHABSIM modeling results over the same 0.1 RM intervals, excluding area where the threshold criterion were not met. Four distinct sub-reach combinations were developed to reflect cumulative effective usable habitat at various RM locations in the lower Tuolumne River PHABSIM study area. These combinations included; Sub-reach 1 (RM 51.9 to RM 46.9), Sub-reach 1–2 (RM 51.9 to RM 43.1), Sub-reach 1–3 (RM 51.9 to RM 39.5), and Sub-reach 1–4 (RM 51.9 to RM 29.1).

4 RESULTS

The water temperature modeling results were combined with PHABSIM modeling results to allow more precise estimates of (1) relationships between air temperature and river temperature at various locations; (2) the length of river channel meeting selected MWAT thresholds (18°C [66.4°F], 20°C [68°F], 22°C [71.6°F], and 24°C [75.2°F]); (3) the length of river channel meeting an 18°C (66.4°F) 7DADM threshold; and (4) the combined temperature/habitat effective usable habitat analysis results at these thresholds for juvenile and adult life stages of oversummering *O. mykiss*.

4.1 Water Temperature Model Results

Daily maximum air temperature during summer months (June-September) over a 42-year period of record dating from October 1970 through September 2012 are shown in Figure 4-1. These results show that July has the greatest number of days where air temperatures exceed 35°C (95°F). The effect of daily maximum air temperatures on predicted daily average water temperatures over a range of flows at various RM locations associated with the downstream boundary of each sub-reach is shown in Figures 4-2 through 4-5. For example, using a daily average water temperature objective of 20°C (68°F) at Robert's Ferry Bridge (RM 39.5) and assuming a maximum daily air temperature of 35°C (95°F), Figure 4-4 shows that this water temperature threshold would be met at a flow release of approximately 300 cfs. However, higher water temperature objectives of 22°C (71.6°F) or 24°C (75.2°F) could be met at RM 39.5 with a flow release of 200 cfs or 150 cfs, respectively. The river flow necessary to attain these same temperature objectives farther downstream at RM 29 would be 600 cfs and 425 cfs, respectively, approximately 300 percent greater.

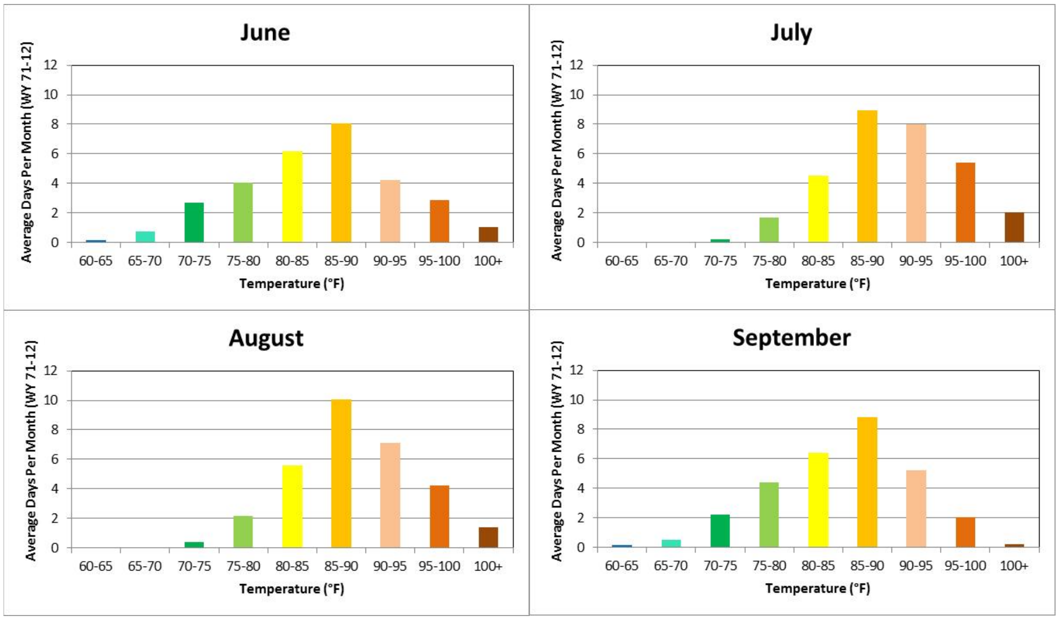

Figure 4-1. Daily maximum air temperatures from the Lower Tuolumne River temperature model (1970–2012).

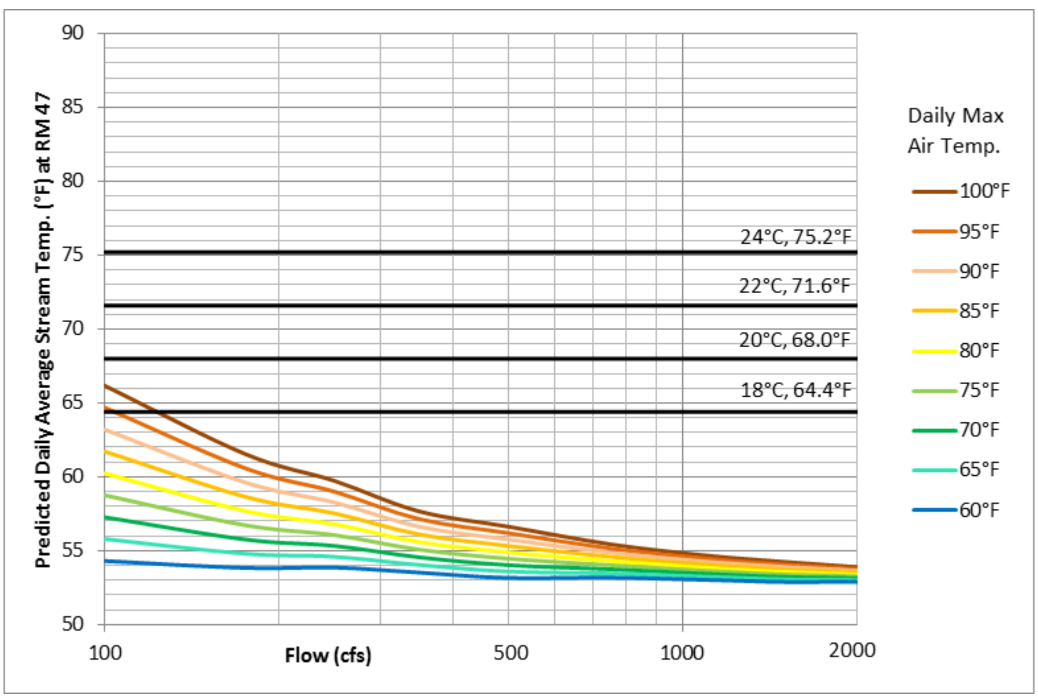

Figure 4-2. Modeled Tuolumne River daily average water temperature associated with daily maximum air temperature over a range of flows at RM 47.

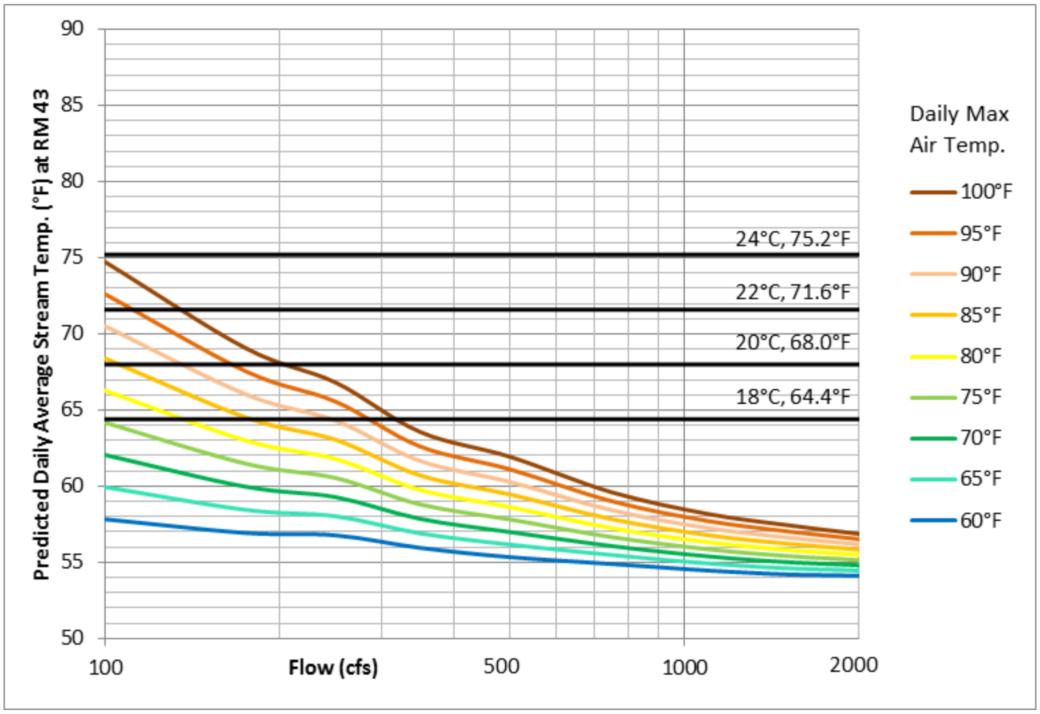

Figure 4-3. Modeled Tuolumne River daily average water temperature associated with daily maximum air temperature over a range of flows at RM 43.

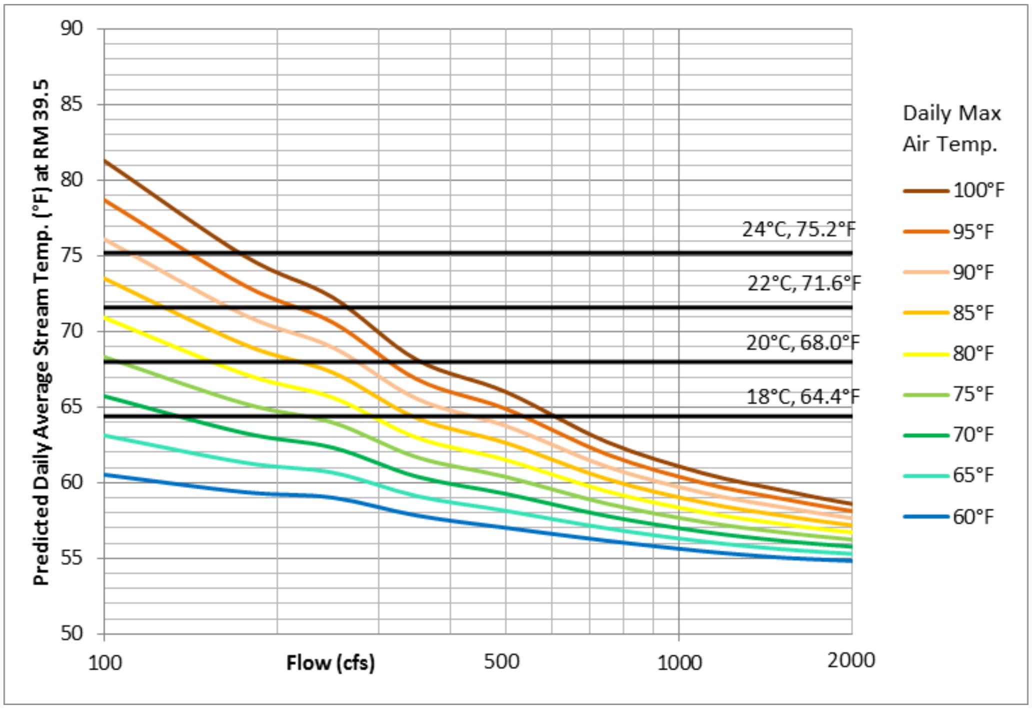

Figure 4-4. Modeled Tuolumne River daily average water temperature associated with daily maximum air temperature over a range of flows at RM 39.5.

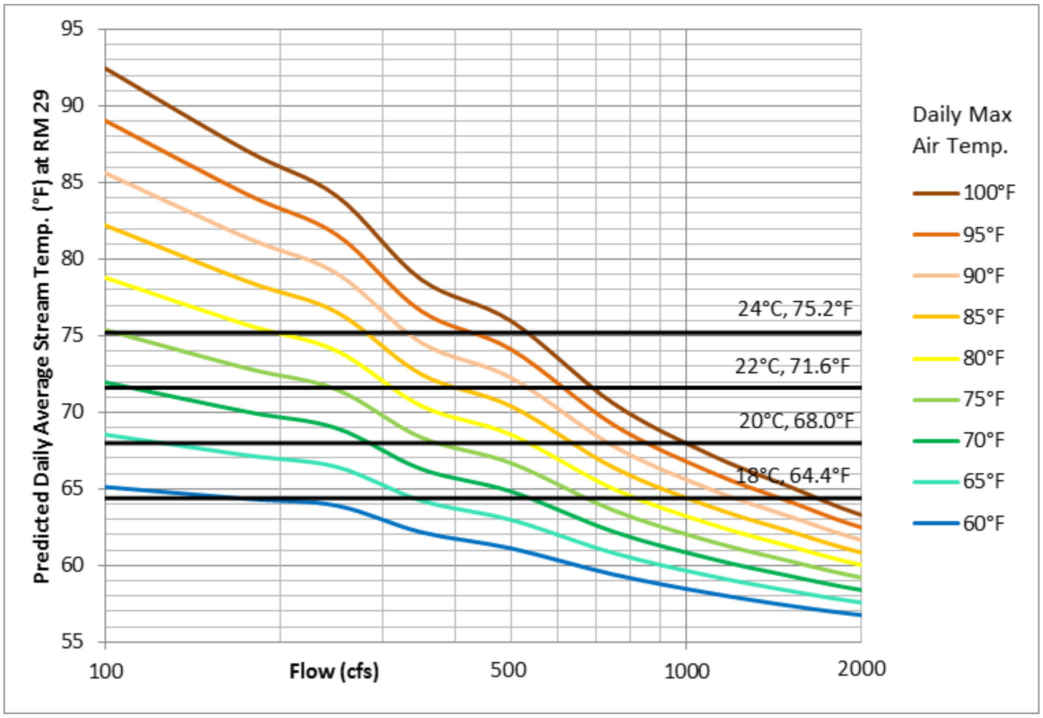

Figure 4-5. Modeled Tuolumne River daily average water temperature associated with daily maximum air temperature over a range of flows at RM 29.0

4.2 Effective Usable Habitat by River Mile

The cumulative effective usable habitat for *O. mykiss* life stages computed for various sub-reaches in the lower Tuolumne River during summer months under each of the selected temperature thresholds is shown in Appendix D, Figures D-1 through D-48. The figures are compiled by life stage (fry, juvenile, adult) and reach designation for each summer month and also include total usable habitat with no temperature threshold applied.

Applying each of the four MWAT temperature thresholds, the results show that for habitats downstream to RM 46.9 (sub-reach 1); there is no change in effective usable area over the entire range of simulated flows for all life stages in any month. Applying an 18°C (64.4°F) 7DADM threshold (using 50% exceedance values) to maintain thermally suitable habitat to sub-reach 1 required flows in excess of 300 cfs in the warmest summer month (July). Although higher flows generally result in greater extent and amounts of effective usable habitat for adult *O. mykiss* (Appendix B), the accompanying increases in velocity result in lower estimates of effective usable habitat for fry and juvenile life stages than any of the MWAT thresholds evaluated (See Figures D-1, D-5, D-9, D-13, D-17, D-21, D-25, D-29, D-33, D-37, D-41, and D-45).

For habitats downstream to RM 43.1 (sub-reaches 1 and 2), there is no change in effective usable area for MWAT thresholds greater than 18°C (64.4°F) over the entire range of simulated flows for all life stages in any month. Effective usable habitat is reduced for a MWAT threshold of 18°C (64.4°F) at flows less than 150 cfs, with the largest reductions occurring in fry and juvenile habitat during July. Applying an 18°C (64.4°F) 7DADM threshold (using 50% exceedance values) to maintain thermally suitable habitat for sub-reaches 1 and 2 required flows in excess of 600 cfs in July. Although higher flows generally result in greater extent and amounts of effective usable habitat for adult *O. mykiss* (Appendix B), the accompanying increases in velocity result in lower estimates of effective usable habitat for fry and juvenile life stages than any of the MWAT thresholds evaluated (See Figures D-2, D-6, D-10, D-14, D-18, D-22, D-26, D-30, D-34, D-38, D-42, and D-46).

For habitats downstream to RM 39.5 (sub-reaches 1, 2, and 3), there is no change in effective usable area with MWAT thresholds greater than 20°C (71.6°F) over the entire range of simulated flows for all life stages in any month. Effective usable habitat is slightly reduced for a MWAT threshold of 20°C (68°F) at flows less than 175 cfs, with the largest reductions occurring in fry and juvenile habitat during July. Effective usable habitat is further reduced applying a MWAT threshold of 18°C (64.4°F) at flows less than 250 cfs, again with the largest reductions occurring in fry and juvenile habitat during July. Applying an 18°C (64.4°F) 7DADM threshold (using 50% exceedance values) to maintain thermally suitable habitat for sub-reaches 1 through 3 required flows in excess of 1,000 cfs in July. Although higher flows generally result in greater extent and amounts of effective usable habitat for adult *O. mykiss* (Appendix B), the accompanying increases in velocity result in lower estimates of effective usable habitat for fry and juvenile life stages than any of the MWAT thresholds evaluated (See Figures D-3, D-7, D-11, D-15, D-19, D-23, D-27, D-31, D-35, D-39, D-43, and D-47).

For habitats downstream to RM 29.1 (sub-reaches 1 through 4), there are reductions in effective usable area shown under all MWAT thresholds except during September with a MWAT threshold of 24°C (75.2°F). During the warmest (July) conditions, flows up to 200 cfs are required to maintain thermally suitable habitat for all life stages at a MWAT threshold of 24°C (75.2°F), with associated flows up to 300 cfs for a MWAT threshold of 22°C (71.6.°F), 425 cfs for a MWAT threshold of 20°C (68°F), and 700 cfs for a MWAT threshold of 18°C (64.4°F). Applying an 18°C (64.4°F) 7DADM threshold (using 50% exceedance values) to maintain thermally suitable habitat for sub-reaches 1 through 4 required flows in excess of 1,050 cfs in July. Although higher flows generally result in greater extent and amounts of effective usable habitat for adult *O. mykiss* (Appendix B), the accompanying increases in velocity result in lower estimates of effective usable habitat for fry and juvenile life stages than for any of the MWAT thresholds evaluated (See Figures D-4, D-8, D-12, D-16, D-20, D-24, D-28, D-32, D-36, D-40, D-44, and D-48).

5 DISCUSSION

Physical habitat modeling (1-D PHABSIM) at flows from 100–1,200 cfs was combined with HEC-RAS water temperature modeling over a 42-year period of record meteorology (1970–2012) to provide estimates of eWUA in the lower Tuolumne River meeting a range of MWAT thresholds ranging from 18–24°C (64.4–75.2°F) during summer (June–September) as well as an 18°C (64.4°F) 7DADM threshold requested by USFWS. For summertime flow ranges from 100 to 250 cfs, thermally suitable habitat approaching 100% of hydraulically suitable habitat is maintained across all months and over all MWAT thresholds downstream to Basso Bridge (RM 46.9), with incremental reductions in usable habitat downstream to Waterford (RM 29.1) as MWAT thresholds decrease. Applying a MWAT temperature threshold of 20°C (68°F), summertime flows of 150 cfs and above would maintain thermally suitable habitat for all life stages of *O. mykiss* downstream to Roberts Ferry Bridge (RM 39.5). However, this estimate is highly sensitive to daily maximum air temperatures and can range up to approximately 350 cfs when air temperatures exceed 37.8°C (100°F).

Estimated flows required to meet the 18°C (64.4°F) 7DADM threshold requested by USFWS (Appendix A) were much higher than any of the MWAT thresholds applied and resulted in higher velocities with correspondingly lower suitability for fry and juvenile *O. mykiss*. For example, maintaining a MWAT of 18°C (64.4°F) downstream to RM 43.1 (sub-reaches 1-2) would require 175 cfs during July in 50% of years, which corresponds to approximately 87% and 100% of the maximum usable habitat for fry and juvenile life stages of *O. mykiss*, respectively (See Figures D-6 and D-22). However, meeting an 18°C (64.4°F) 7DADM threshold in 50% of years at RM 43.1 would require flows of 650 cfs during July, which corresponds to only 67% and 75% of the maximum usable habitat for these life stages. Although higher flows to meet lower water temperature thresholds at RM 43.1 and other locations would generally result in greater amounts of usable habitat for adult *O. mykiss* (See Figures D-33 through D-48), the corresponding increases in velocity at those flows result in reduced amounts of hydraulically suitable habitat for fry and juvenile life stages in all sub-reaches evaluated.

As discussed in the *Assessment of Don Pedro Project Operations to Meet EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards* (as attached to TID/MID 2017a), potential re-operation of the Don Pedro Project to meet USEPA (2003) temperature recommendations was previously shown to be infeasible under a range of potential scenarios evaluated. Application of the USEPA (2003) water temperature recommendations to HEC-RAS water temperature modeling predictions within the summer base flow ranges in the current FERC (1996) flow schedule (50–250 cfs) would suggest that only the first few miles downstream of La Grange Diversion Dam (RM 52.2) are thermally suitable for *O. mykiss* fry and juvenile life stages during summer. This conclusion is at odds with long-term snorkel survey results for these flow ranges that consistently show *O. mykiss* present in sampling units downstream to RM 42 during summer in all but the driest water year types since 1999 (TID/MID 2015, Report 2014-5).

The Districts have recently completed a study of thermal performance of wild juvenile *O. mykiss* in the lower Tuolumne River (Farrell et al. 2017), which has provided specific empirical data to better evaluate site-specific water temperature objectives for the lower Tuolumne River. Results of Farrell et al. were used to improve the scope of the temperature thresholds included in this document. For example, the empirical data obtained by testing wild Tuolumne River juvenile *O. mykiss* demonstrated that fish tested at 24°C (75.2°F) performed nearly as well as fish tested at cooler temperatures and attained AAS within 5% of the peak values estimated. Using this temperature as an upper threshold for daily average water temperatures, thermally suitable conditions could be maintained as far downstream as RM 39.5 using flows of 150 cfs even when maximum daily air temperatures exceeded 37.8°C (100°F) (see Figure 4-4).

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Appendices

Appendix A

Draft Report Comment Summary and Responses

Pursuant to the requirements of the FERC Order, the Draft *Lower Tuolumne River Instream Flow Study–Evaluation of Effective Usable Habitat Area for over-summering O. mykiss* was circulated for a 30-day review period (February 27, 2015 – April 1, 2015) to the resource agencies and interested parties. Following the 30-day review period, the USFWS (2015) provided comments on April 8, 2015, which have been addressed in this final report. No other comments were received as of the date of this filing. Excepted comments provided by USFWS and Districts' responses are provided in Table A-1 below.

Table A-1. Excerpts and responses to comments on the February 2015 Draft Report evaluating effective usable habitat area for over-summering *O. mykiss*

No.	USFWS comment	Districts' reply
General comments		
1	Page 2, Section 3.1: We recommend the use of the EPA (2003) 18 degrees Centigrade criterion for the effective habitat analysis. Development of an alternative water temperature quality criterion would need to consider all of the following: Genetic adaptation in temperature tolerance, physiological indicators of thermal adaptation, application of biomarkers, thermal tolerance, growth, reproduction and intergenerational effects, movement and migration, adaptation in thermal tolerance, adaptations in seasonality, effects of fitness on the population, interactions among fish species, food web dynamics, and disease and parasites (McCullough et al 2009). In addition, a new water temperature criterion would need to address how the degree of anadromy is affected by water temperatures. Farrell et al. (2014) investigated the effects of water temperature on aerobic scope, and was the basis for the Districts' proposal to use a water temperature criterion higher than 18 degrees Centrigrade. Farrell et al. (2014) only addresses one aspect of growth (namely aerobic scope).	The purpose of this study report was to meet requirements of the July 16, 2009 FERC order "to determine the downstream extent of thermally suitable habitat to protect summer juvenile *Oncorhynchus mykiss*, rearing under various flow conditions and to determine flows necessary to maintain water temperatures at or below 68 degrees Fahrenheit from La Grange Dam to Roberts Ferry Bridge". At the request of USFWS, we have included the USEPA (2003) 18°C (64.4°F) 7DADM as an additional evaluation threshold. Discussion of the results from in Farrell et al. (2017)[3] are used to provide context of relevant site-specific information that indicates potential thermal adaptation by *O. mykiss* in the lower Tuolumne River to higher temperatures than recommended by USEPA (2003). The results of this report are not intended to support development of an alternate water temperature criterion and we recognize the complexity in the decision-making underlying setting thermal criteria. The Districts will provide further discussion of the Farrell et al (2017) report findings in future filings with the Commission.
2	Use of a higher water temperature criterion is inconsistent with the low populations of *O. mykiss* in the Tuolumne River. Specifically, data in the 2009 TID/MID snorkeling report shows, from 1982 to 2009 no *O. mykiss* were observed throughout all sites (RM 25 up to 52 Dam) in 27% (7 of 26) of years. In addition, using pooled data (counts from all seasons in a year), less than 10 total *O. mykiss* were observed riverwide in nearly half (46%, 12 of 26) of years. Further, less than 100 fish were observed (river wide) in 65% (17 of 26) of years.	With regard to the comment references to river wide counts of *O. mykiss* in summer snorkel surveys, it should be noted that these surveys have been conducted using several survey designs since 1982 and summer base flows were increased as part of the July 31, 1996 FERC Order. For both of these reasons, comparisons of individual counts and river wide detection frequencies across the entire period of record are misleading and the frequency and numbers of *O. mykiss* observed have increased since adoption of the 1996 FERC Order. The Districts maintain that direct fish observations of rearing *O. mykiss* have occurred over a range of temperatures during summer, including temperatures as

[3] On February 27, 2015, the Districts circulated a draft version of the Lower Tuolumne River Instream Flow Study – Evaluation of Effective Usable Habitat Area for over-summering *O. mykiss* Study Report for relicensing participants' review. This draft report incorrectly cited Farell (2015) as Farrell (2014). In 2017, Farrell (2015) was finalized. All references to Farrell (2014) in this final report have been updated to Farrell (2017) so as to reference the final version of the Farrell et al. study report.

No.	USFWS comment	Districts' reply
		high as 25.5°C (77°F). These observations provide an indication of potential thermal adaptation of *O. mykiss* in the Tuolumne River. Because Farrell et al (2017) showed relatively high swimming performance of juvenile *O. mykiss* at temperatures up to 24°C (75.2°F), this suggests that other factors than water temperature may explain variations in fish density by river mile. For example, increased habitat suitability for predatory fish species in downstream habitats may be limiting the population in these areas due to predation upon juvenile life stages. Counts and relative density of *O. mykiss* reported in annual snorkel summary reports are consistently lower in downstream habitats (downstream of RM 40), even in years such as 2011 combining higher population numbers and high flows that would be expected to reduce water temperatures in these locations.
3	*Page 3, Section 3.2*: As discussed in our April 18, 2013 and February 26, 2014 letters (Attachments 1 and 2) on the Districts' Lower Tuolumne River Instream Flow Study (Stillwater Sciences, 2013), the WUA results used in this report are likely biased toward low flows because the habitat suitability criteria did not include cover and adjacent velocity, and the depth and velocity criteria were not developed using logistic regression to correct for low availability of faster and deeper conditions. Effective habitat should be quantified for the entire anadromous portion of the Tuolumne River (from La Grange powerhouse to the confluence of the Tuolumne with the San Joaquin River).	The Districts' acknowledge this comment and refer to Appendix K of the Lower Tuolumne River Instream Flow Study (Stillwater Sciences 2013) for a detailed response to the comments received in letters from the USFWS dated April 8, 2013 and February 26, 2014.

No.	USFWS comment	Districts' reply
4	Page 4, Section 3.4: The effective habitat analysis should use 7 day average maximum daily temperature (7DADM) instead of maximum weekly average temperature (MWAT), since the EPA (2003) criterion is for 7DADM. Effective habitat should be calculated for a range of meteorological conditions (for example 20% and 80% exceedance of 7DADM), rather than just 50% exceedance, as used in the report.	At the request of USFWS, the effective habitat analysis now includes an 18°C (64.4°F) 7DADM threshold calculated using the 20%, 50%, and 80% exceedance values over the 42-year period of record (1970–2012).
5	Of the information given in the report, we would recommend using the 18 degrees Centigrade curves in Figures C-36, C-40, C-44 and C-48, since the adult life stage is likely the limiting life stage for *O. mykiss* in the Tuolumne River and conditions should be protective for the entire study area (sub reaches 1-4).	Although this report does not directly evaluate operational feasibility of various temperature objectives (See TID/MID 2017a, Attachment A), maintenance of an 18°C (64.4°F) MWAT to RM 29 would require flows in excess of 650 cfs during the warmest summer months (July). Although this would result in habitat maximizing flows for adult *O. mykiss*, it would reduce usable habitat for fry and juvenile *O. mykiss* to 67% and 75% of maximum, respectively. The Districts previously evaluated potential re-operation of the Don Pedro Project to meet USEPA (2003) temperature recommendations which were shown to be infeasible under a range of potential scenarios evaluated (TID/MID 2017a, Attachment A).

Appendix B

1-D PHABSIM Weighted Usable Area Results by Sub-reach in the lower Tuolumne River

Table B-1. Weighted usable area (sq ft/1,000 ft) results for *O. mykiss* in Sub-reach 1 (RM 51.9 to RM 46.9).

Simulated discharge (cfs)	*O. mykiss* fry	*O. mykiss* juvenile	*O. mykiss* adult
50	60,590	55,485	13,876
75	55,359	59,745	18,777
100	51,170	62,297	22,995
125	48,063	63,790	26,694
150	46,013	64,422	29,806
175	44,051	64,404	32,481
200	42,554	63,738	34,721
225	41,319	63,016	36,720
250	40,134	62,088	38,455
275	38,918	61,093	39,991
300	37,850	60,075	41,240
325	36,988	59,046	42,258
350	36,195	57,943	43,101
375	35,445	56,796	43,845
400	34,878	55,625	44,464
425	34,367	54,549	44,987
450	33,974	53,621	45,429
475	33,774	52,604	45,789
500	33,509	51,735	46,067
550	33,114	50,242	46,486
600	33,134	48,734	46,734
650	33,392	47,485	46,864
700	33,323	46,291	46,872
750	33,381	45,093	46,862
800	33,567	44,222	46,856
850	33,280	43,494	46,775
900	33,393	43,073	46,657
1,000	33,574	42,207	46,320
1,100	33,465	41,953	45,865
1,200	33,933	41,952	45,387

Table B-2. Weighted usable area (sq ft/1,000 ft) results for *O. mykiss* in Sub-reach 2 (RM 46.9 to RM 43.1).

Simulated discharge (cfs)	*O. mykiss* fry	*O. mykiss* juvenile	*O. mykiss* adult
50	50,517	49,690	15,316
75	46,057	52,039	20,459
100	42,868	53,226	24,665
125	40,569	53,877	28,173
150	39,036	54,007	30,916
175	37,600	53,636	32,962
200	36,312	52,938	34,489
225	35,326	52,331	35,736
250	34,484	51,590	36,785
275	33,575	50,824	37,686
300	32,812	50,108	38,380
325	32,252	49,306	38,885
350	31,764	48,417	39,256
375	31,328	47,545	39,584
400	31,000	46,709	39,835
425	30,711	45,923	40,037
450	30,492	45,279	40,209
475	30,427	44,571	40,337
500	30,135	43,909	40,437
550	29,626	42,848	40,587
600	29,487	41,770	40,654
650	29,743	41,048	40,665
700	29,910	40,248	40,601
750	30,558	39,435	40,509
800	31,405	38,928	40,437
850	31,699	38,559	40,300
900	32,537	38,367	40,150
1,000	34,155	38,308	39,811
1,100	34,792	38,559	39,446
1,200	36,261	39,207	39,113

Table B-3. Weighted usable area (sq ft/1,000 ft) results for *O. mykiss* in Sub-reach 3 (RM 43.1 to RM 39.5).

Simulated discharge (cfs)	*O. mykiss* fry	*O. mykiss* juvenile	*O. mykiss* adult
50	53,089	51,063	15,649
75	49,432	53,708	21,136
100	46,056	55,127	25,671
125	43,289	56,108	29,431
150	41,124	56,469	32,330
175	39,009	56,283	34,529
200	37,073	55,771	36,156
225	35,568	55,267	37,433
250	34,319	54,518	38,468
275	33,070	53,730	39,290
300	32,087	52,963	39,906
325	31,400	52,056	40,311
350	30,842	51,013	40,562
375	30,352	49,980	40,733
400	29,980	49,028	40,790
425	29,660	48,094	40,789
450	29,412	47,281	40,734
475	29,342	46,398	40,631
500	29,045	45,554	40,518
550	28,510	44,103	40,210
600	28,399	42,626	39,827
650	28,647	41,606	39,414
700	28,787	40,519	38,991
750	29,387	39,405	38,595
800	30,191	38,650	38,277
850	30,539	38,063	37,930
900	31,428	37,613	37,624
1,000	33,138	37,174	37,019
1,100	33,886	37,106	36,481
1,200	35,450	37,424	35,995

Table B-4. Weighted usable area (sq ft/1,000 ft) results for *O. mykiss* in Sub-reach 4 (RM 39.5 to RM 29.1).

Simulated discharge (cfs)	*O. mykiss* fry	*O. mykiss* juvenile	*O. mykiss* adult
50	53,629	53,735	15,807
75	49,676	56,226	21,159
100	46,284	57,463	25,663
125	43,822	58,259	29,443
150	41,980	58,526	32,417
175	40,229	58,281	34,766
200	38,639	57,615	36,649
225	37,432	57,034	38,324
250	36,438	56,290	39,779
275	35,409	55,562	41,065
300	34,536	54,826	42,090
325	33,870	54,009	42,893
350	33,296	53,076	43,546
375	32,767	52,119	44,123
400	32,348	51,231	44,598
425	31,991	50,400	45,012
450	31,725	49,675	45,359
475	31,614	48,904	45,635
500	31,289	48,172	45,859
550	30,709	46,962	46,208
600	30,488	45,724	46,448
650	30,488	44,787	46,612
700	30,417	43,857	46,687
750	30,709	42,957	46,725
800	31,117	42,288	46,767
850	31,256	41,763	46,747
900	31,814	41,354	46,689
1,000	32,957	40,652	46,438
1,100	33,314	40,453	46,104
1,200	34,176	40,607	45,694

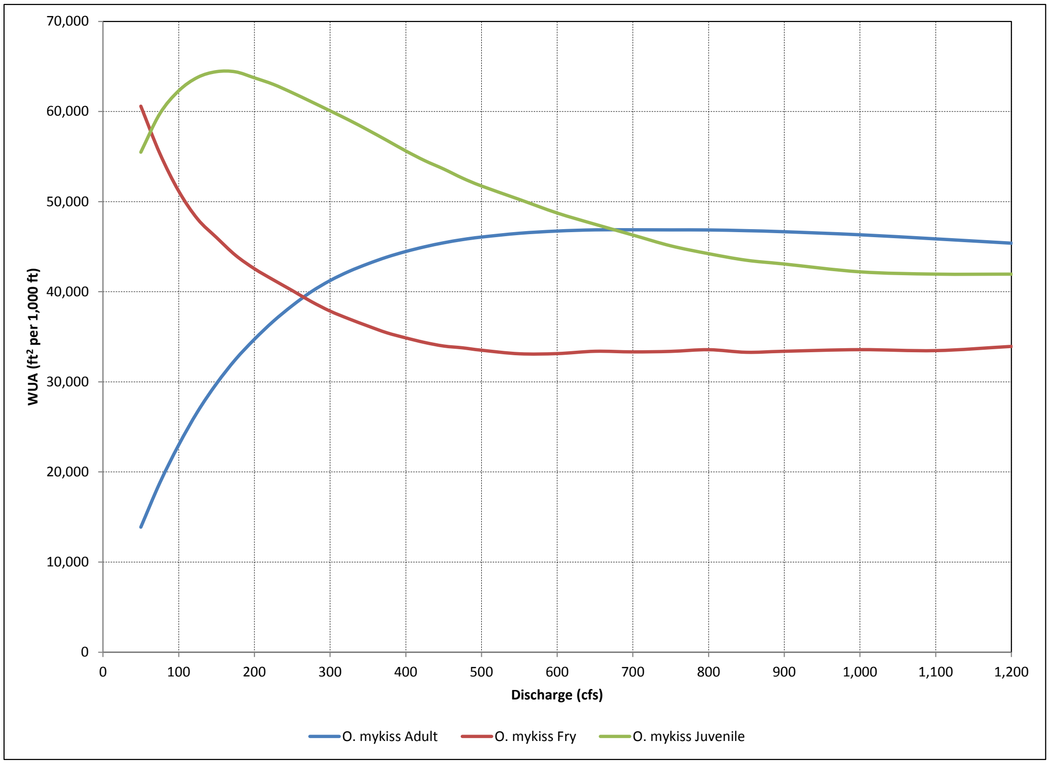

Figure B-1. *O. mykiss* weighted usable area in sub-reach 1 (RM 51.9 to RM 46.9).

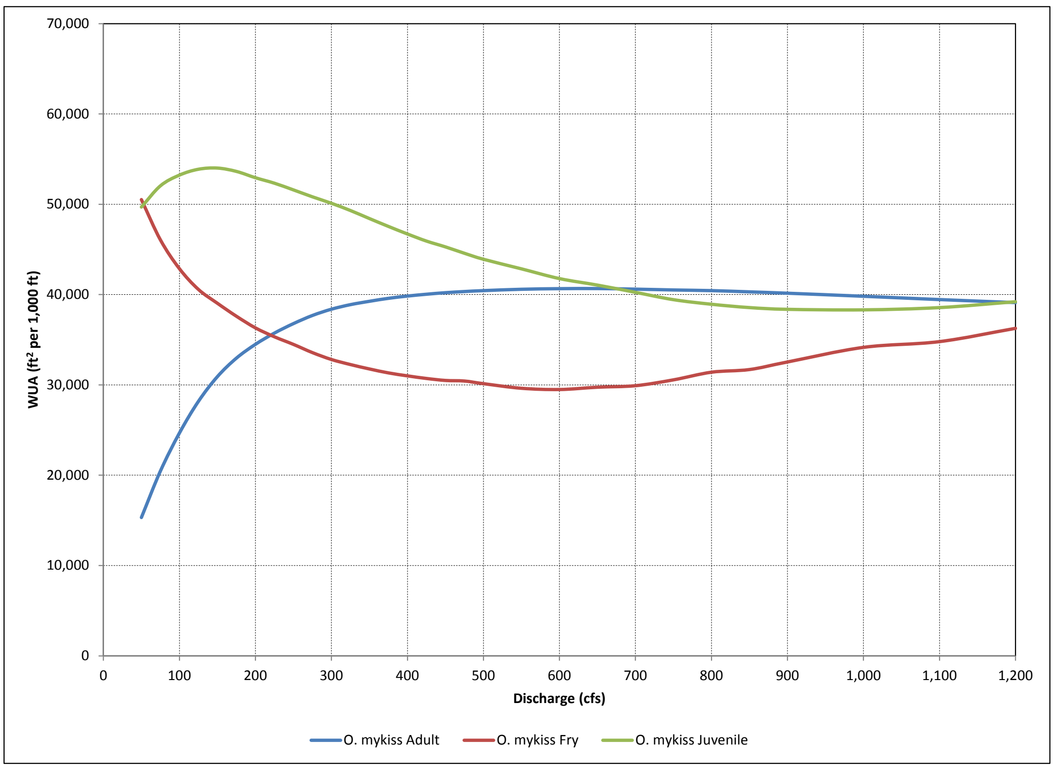

Figure B-2. *O. mykiss* weighted usable area in sub-reach 2 (RM 46.9 to RM 43.1).

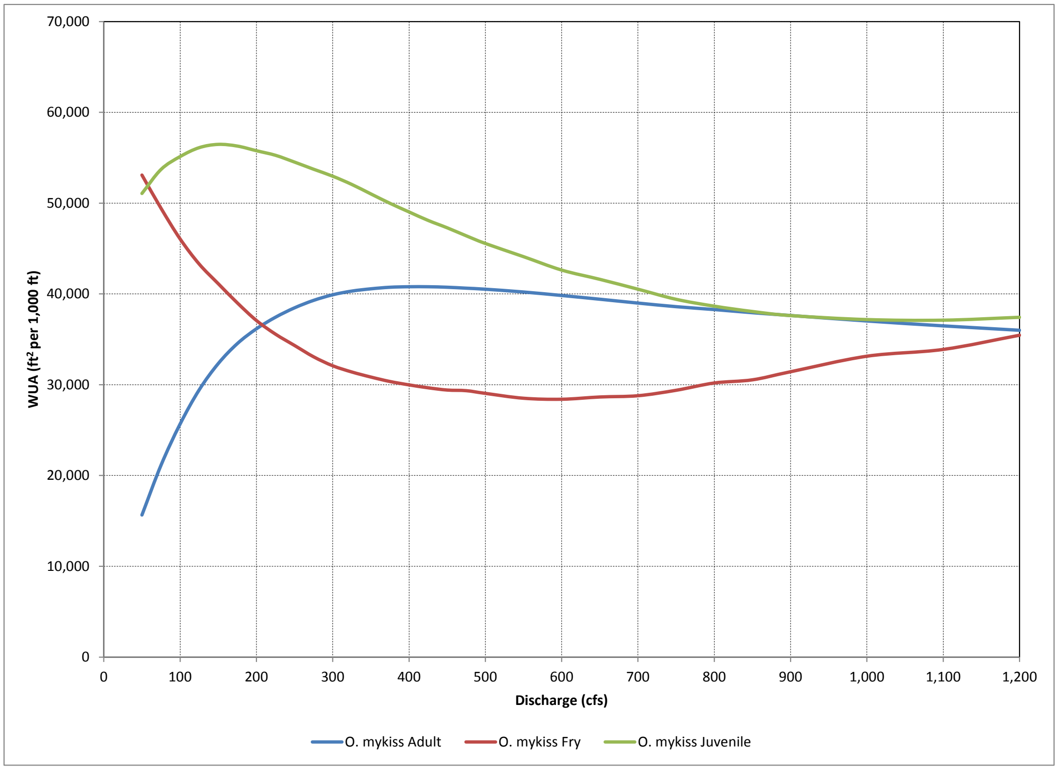

Figure B-3. *O. mykiss* weighted usable area in sub-reach 3 (RM 43.1 to RM 39.5).

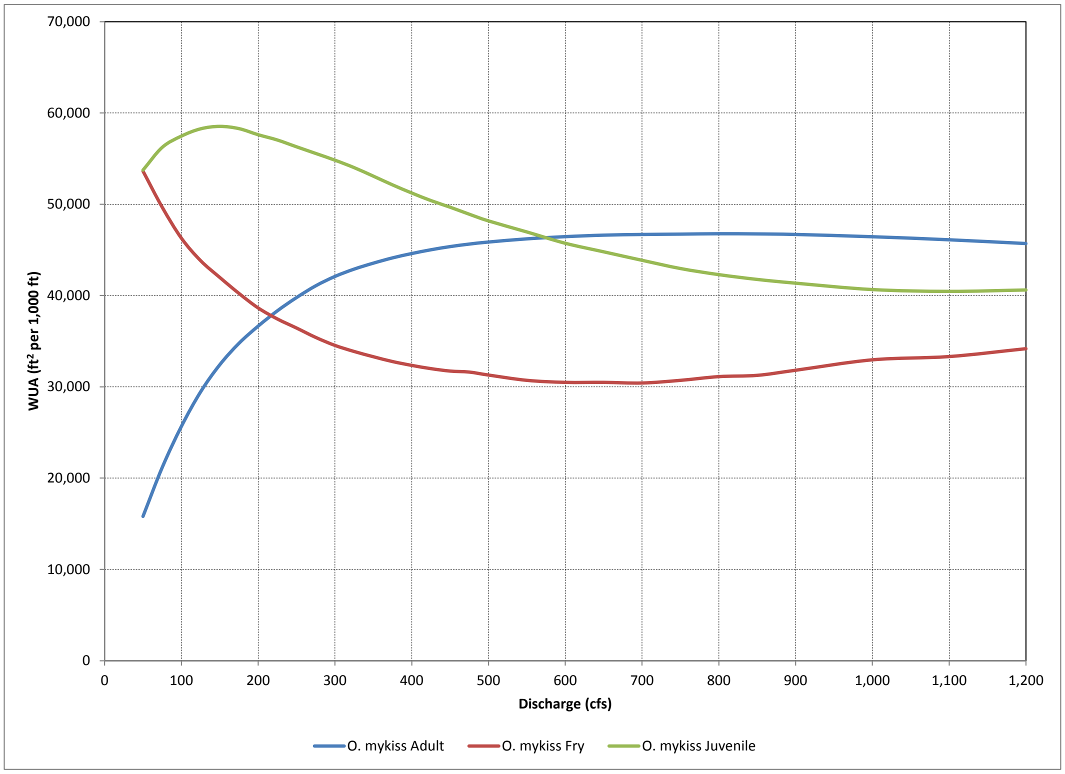

Figure B-4. *O. mykiss* weighted usable area in sub-reach 4 (RM 39.5 to RM 21.9).

Appendix C

1-D PHABSIM Transect Weighting by Sub-reach in the lower Tuolumne River

Table C-1 Transect weighting used for reach models 1–4 (RM 52.2–24.6).

Sub-reach	Channel form	Habitat type	Length (ft)	% of total	Transects	Weight per transect	Weight per habitat
1	Bar Complex	Glide	226	0.88%	2	0.44%	0.88%
		Pool	739	2.87%	5	0.57%	2.87%
		Riffle	3,050	11.87%	7	1.70%	11.87%
		Run	2,027	7.89%	6	1.31%	7.89%
	Flatwater	Glide	1,758	6.84%	3	2.28%	6.84%
		Pool	6,714	26.12%	6	4.35%	26.12%
		Riffle	4,532	17.63%	2	8.81%	17.63%
		Run	6,659	25.91%	9	2.88%	25.91%
Sub-reach 1 (RM 51.9–46.9) Total			**25,705**	**100.00%**	**40**		**100.00%**
2	Bar Complex	Glide	0	0.00%	2	0.00%	0.00%
		Pool	561	2.62%	5	0.52%	2.62%
		Riffle	4,303	20.07%	7	2.87%	20.07%
		Run	4,927	22.98%	6	3.83%	22.98%
	Flatwater	Glide	126	0.59%	3	0.20%	0.59%
		Pool	2,886	13.46%	6	2.24%	13.46%
		Riffle	575	2.68%	2	1.34%	2.68%
		Run	8,059	37.59%	9	4.18%	37.59%
Sub-reach 2 (RM 46.9–43.1) Total			**21,437**	**100.00%**	**40**		**100.00%**
3	Bar Complex	Glide	572	3.31%	2	1.66%	3.31%
		Pool	1,410	8.16%	5	1.63%	8.16%
		Riffle	3,394	19.65%	7	2.81%	19.65%
		Run	4,281	24.78%	6	4.13%	24.78%
	Flatwater	Glide	944	5.46%	3	1.82%	5.46%
		Pool	0	0.00%	6	0.00%	0.00%
		Riffle	201	1.17%	2	0.58%	1.17%
		Run	6,472	37.47%	9	4.16%	37.47%
Sub-reach 3 (RM 43.1–39.5) Total			**17,275**	**100.00%**	**40**		**100.00%**
4	Bar Complex	Glide	1,295	2.31%	2	1.15%	2.31%
		Pool	6,810	12.13%	5	2.43%	12.13%
		Riffle	10,197	18.16%	7	2.59%	18.16%
		Run	12,615	22.46%	6	3.74%	22.46%
	Flatwater	Glide	591	1.05%	3	0.35%	1.05%
		Pool	10,655	18.97%	6	3.16%	18.97%
		Riffle	1,278	2.27%	2	1.14%	2.27%
		Run	12,724	22.65%	9	2.52%	22.65%
Sub-reach 4 (RM 39.5–21.9) Total			**56,165**	**100.00%**	**40**		**100.00%**

Appendix D

Effective Weighted Usable Area Results by Sub-reach in the lower Tuolumne River during summer (1970–2012) using selected water temperature thresholds from 18-24°C

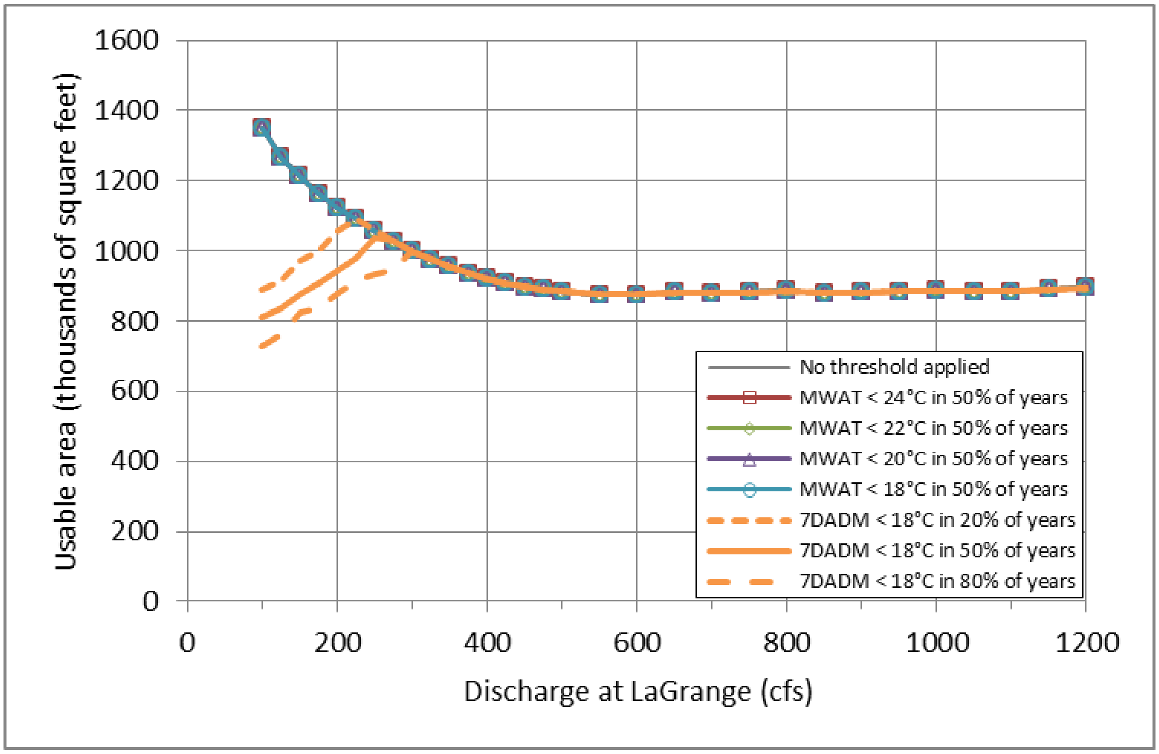

Figure D-1. Effective habitat for *O. mykiss* fry in June for habitats in sub-reach 1 (RM 51.9 to RM 46.9) meeting selected temperature thresholds.

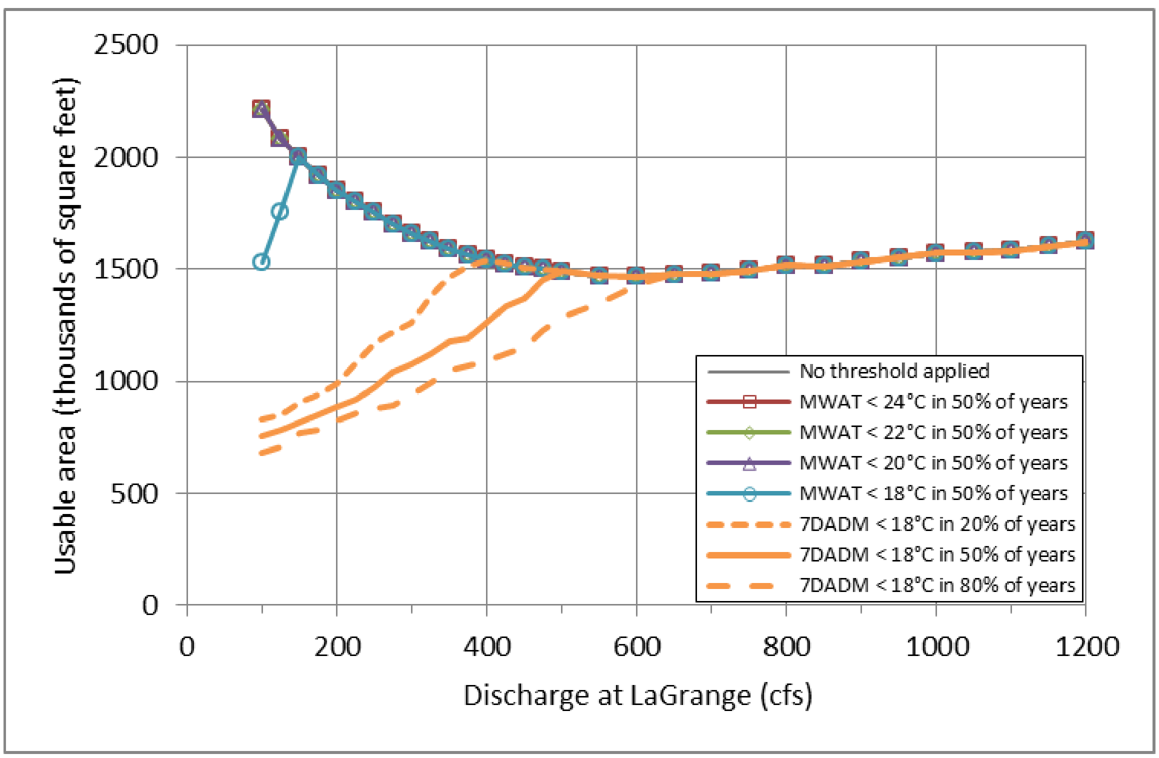

Figure D-2. Effective habitat for *O. mykiss* fry in June for habitats in sub-reaches 1-2 (RM 51.9 to RM 43.1) meeting selected temperature thresholds.

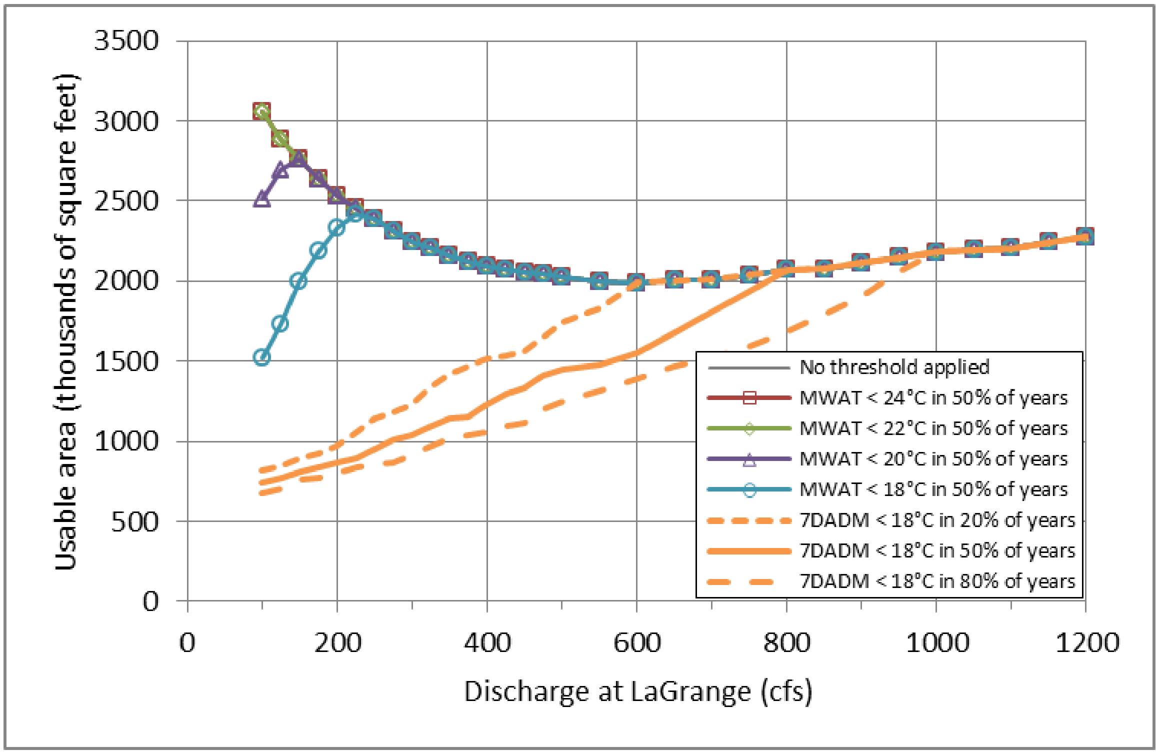

Figure D-3. Effective habitat for *O. mykiss* fry in June for habitats in sub-reaches 1-3 (RM 51.9 to RM 39.5) meeting selected temperature thresholds.

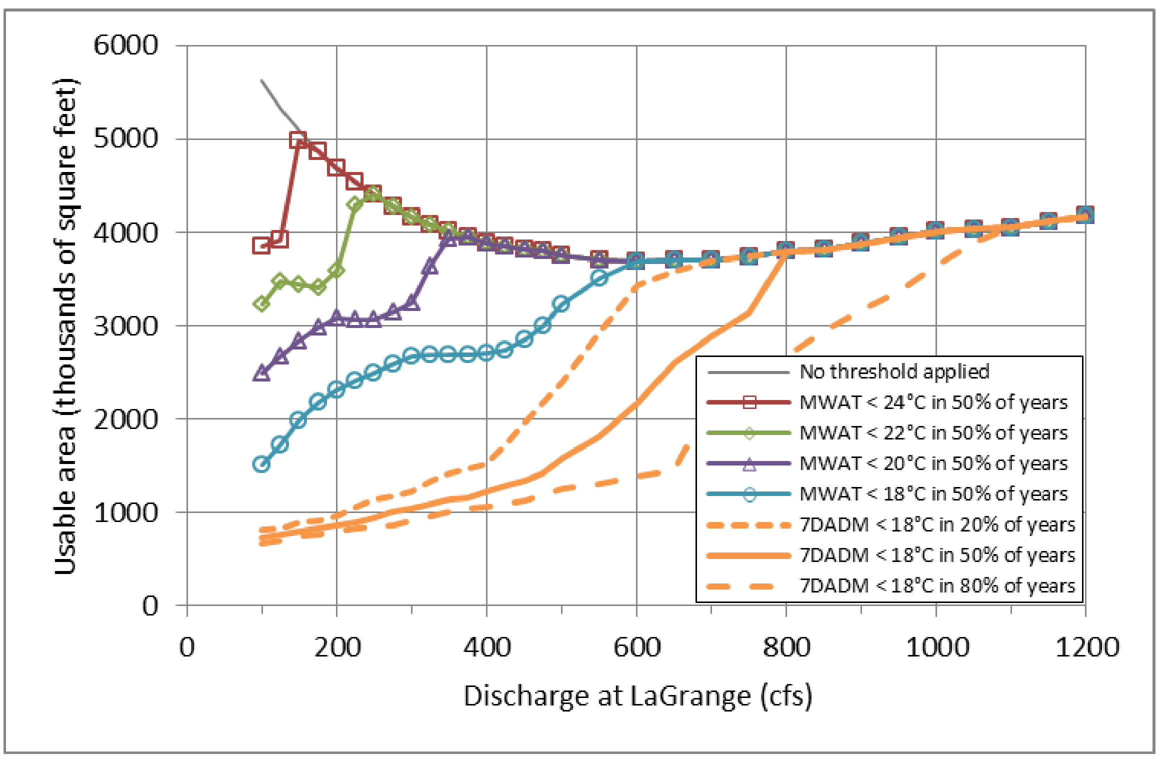

Figure D-4. Effective habitat for *O. mykiss* fry in June for habitats in sub-reaches 1-4 (RM 51.9 to RM 29.1) meeting selected temperature thresholds.

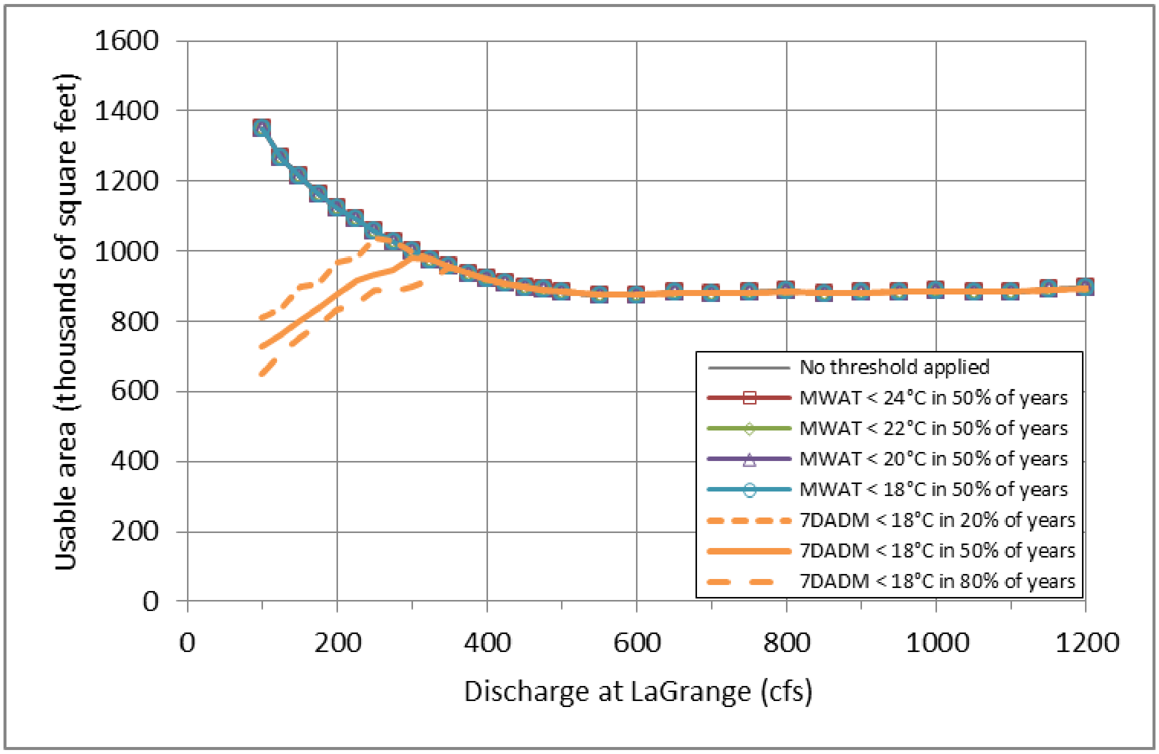

Figure D-5. Effective habitat for *O. mykiss* fry in July for habitats in sub-reach 1 (RM 51.9 to RM 46.9) meeting selected temperature thresholds.

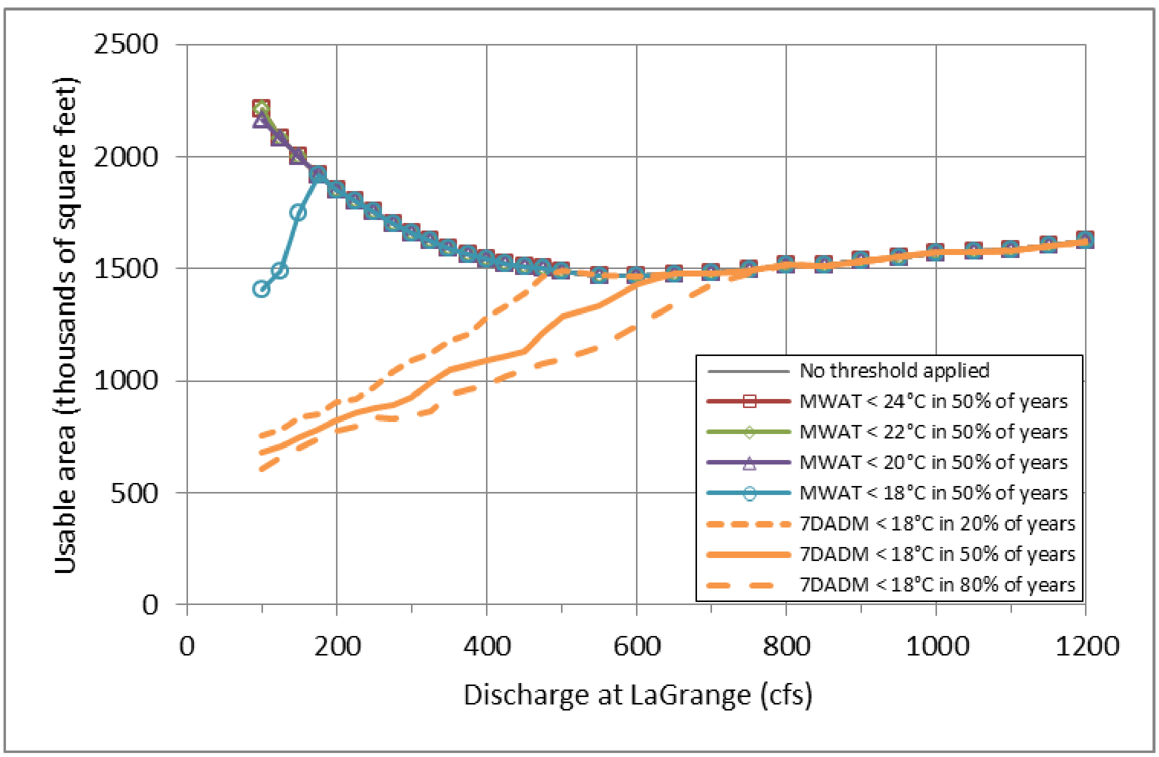

Figure D-6. Effective habitat for *O. mykiss* fry in July for habitats in sub-reaches 1-2 (RM 51.9 to RM 43.1) meeting selected temperature thresholds.

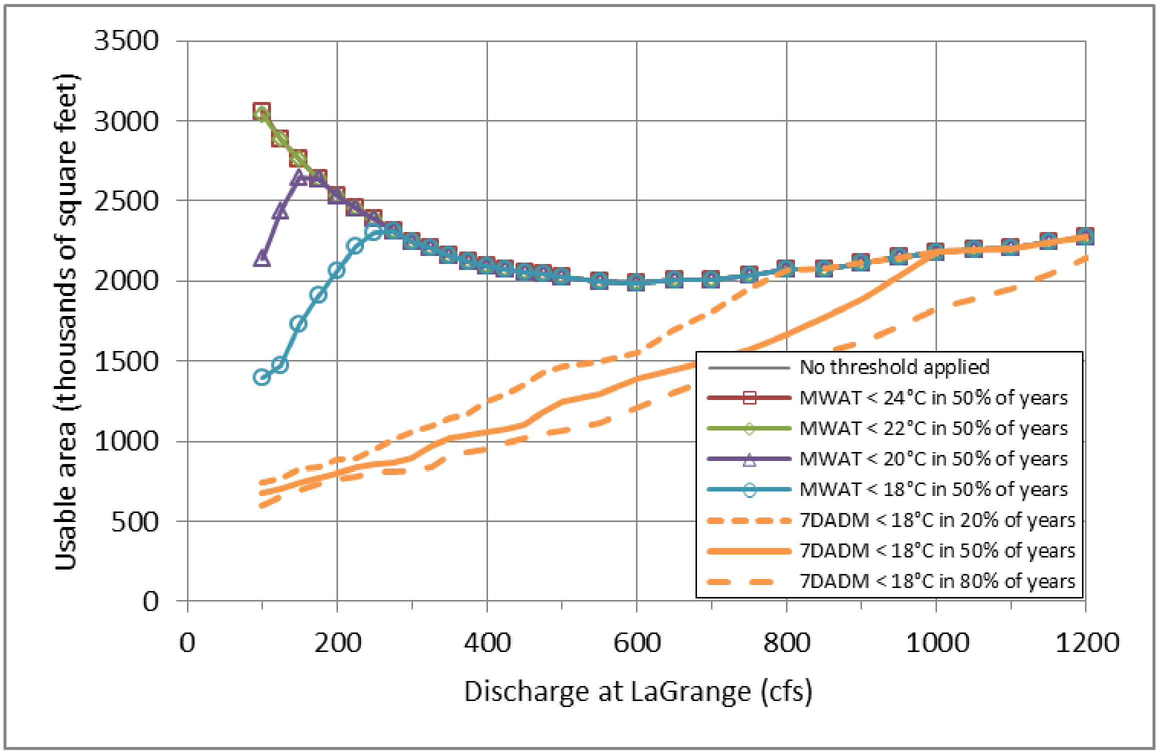

Figure D-7. Effective habitat for *O. mykiss* fry in July for habitats in sub-reaches 1-3 (RM 51.9 to RM 39.5) meeting selected temperature thresholds.

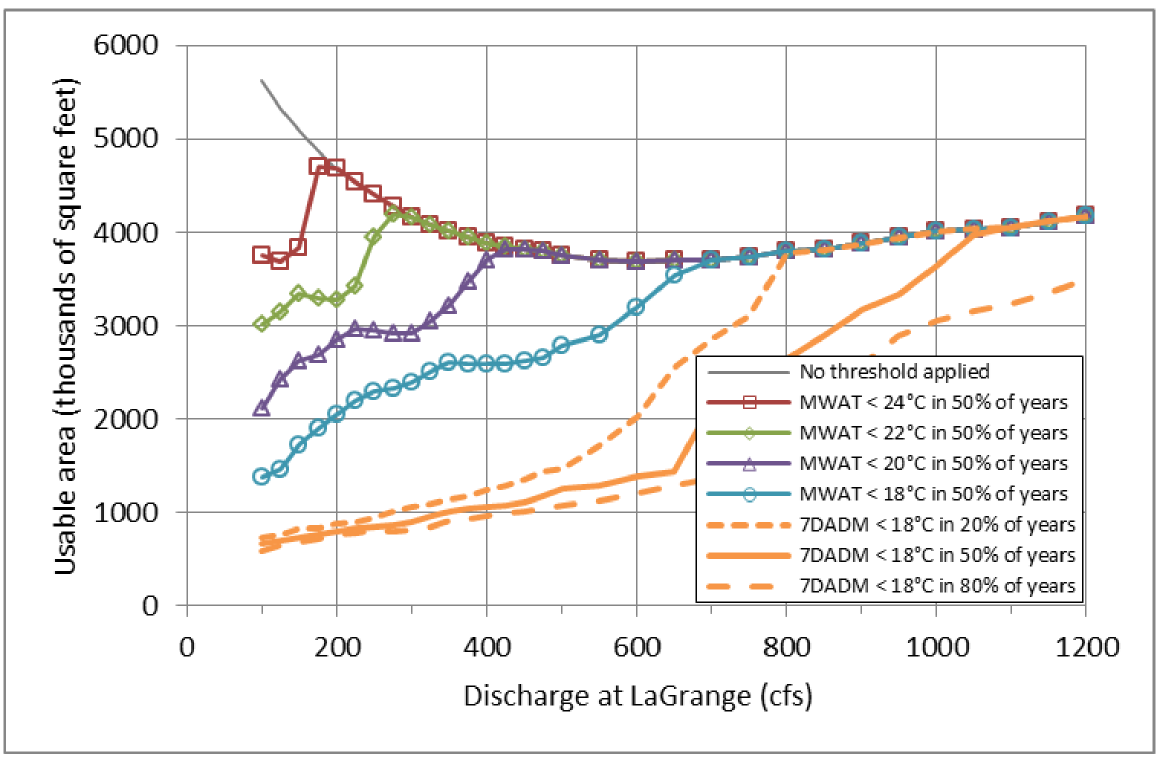

Figure D-8. Effective habitat for *O. mykiss* fry in July for habitats in sub-reaches 1-4 (RM 51.9 to RM 29.1) meeting selected temperature thresholds.

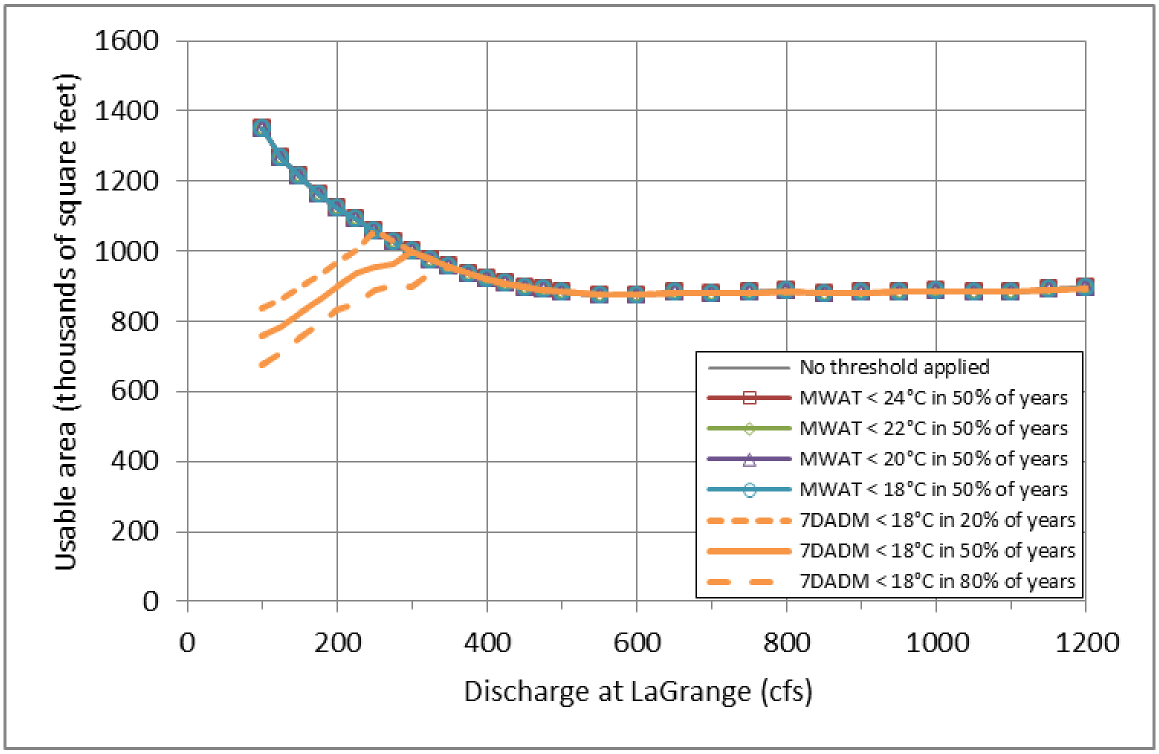

Figure D-9. Effective habitat for *O. mykiss* fry in August for habitats in sub-reach 1 (RM 51.9 to RM 46.9) meeting selected temperature thresholds.

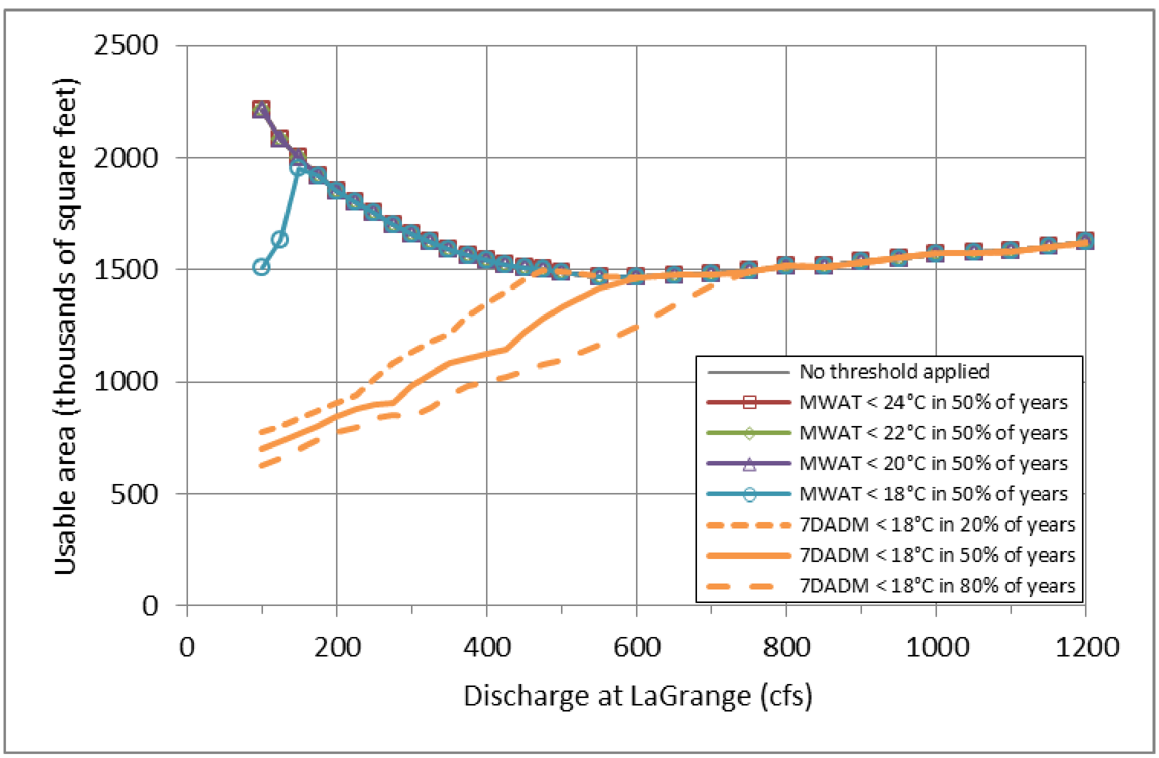

Figure D-10. Effective habitat for *O. mykiss* fry in August for habitats in sub-reaches 1-2 (RM 51.9 to RM 43.1) meeting selected temperature thresholds.

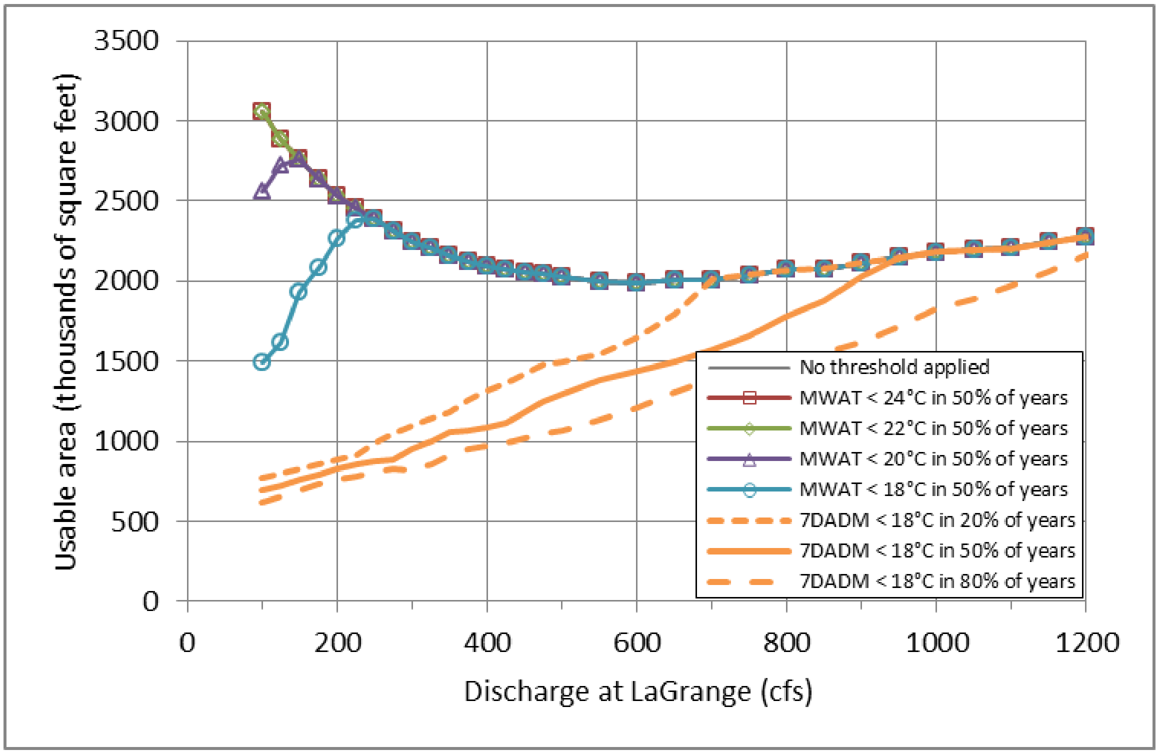

Figure D-11. Effective habitat for *O. mykiss* fry in August for habitats in sub-reaches 1-3 (RM 51.9 to RM 39.5) meeting selected temperature thresholds.

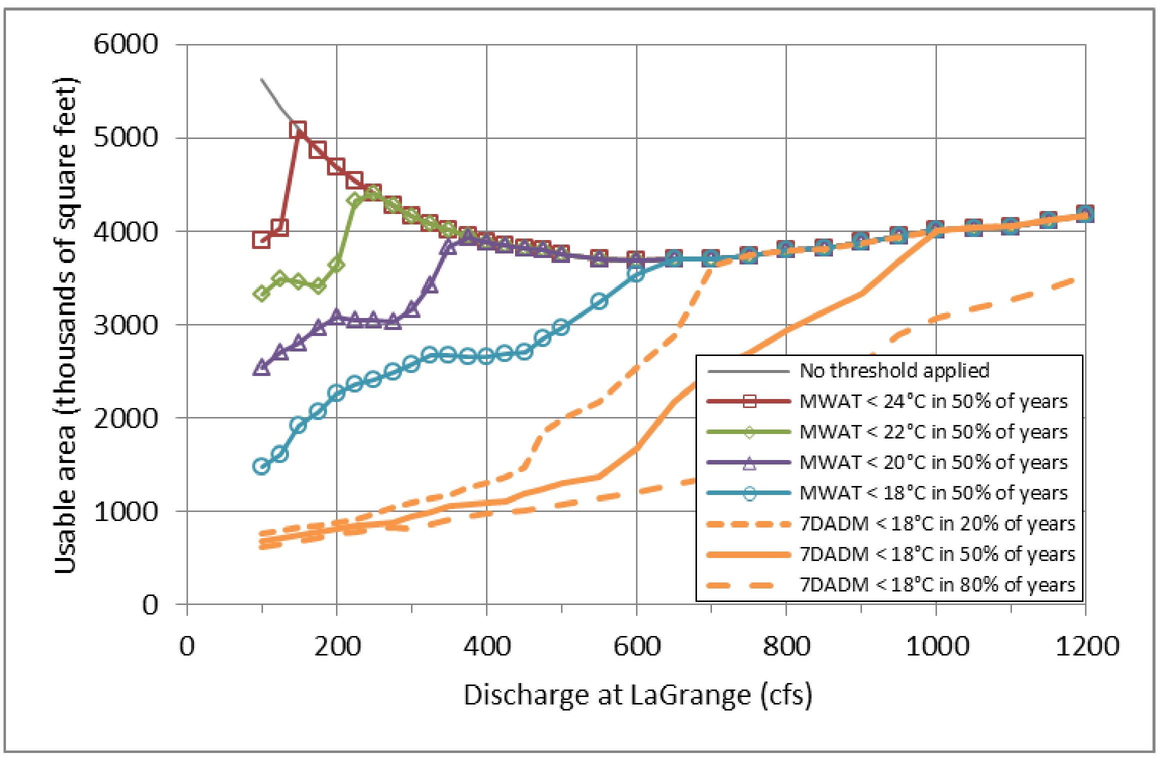

Figure D-12. Effective habitat for *O. mykiss* fry in August for habitats in sub-reaches 1-4 (RM 51.9 to RM 29.1) meeting selected temperature thresholds.

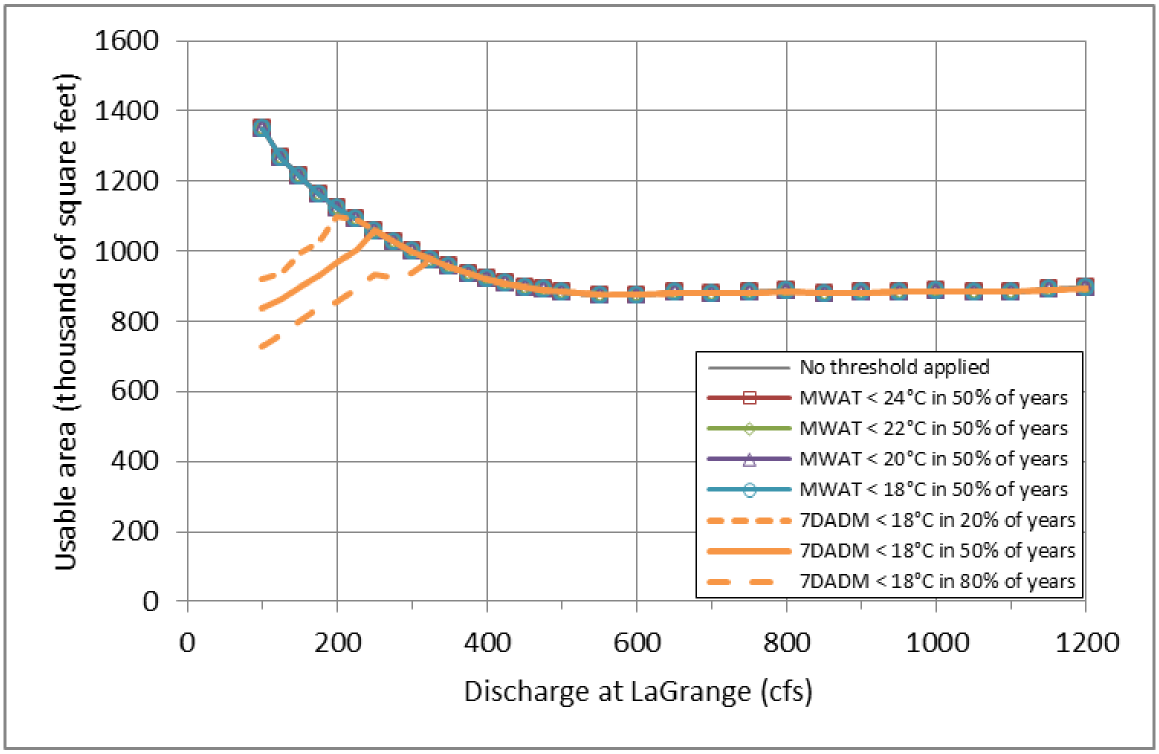

Figure D-13. Effective habitat for *O. mykiss* fry in September for habitats in sub-reach 1 (RM 51.9 to RM 46.9) meeting selected temperature thresholds.

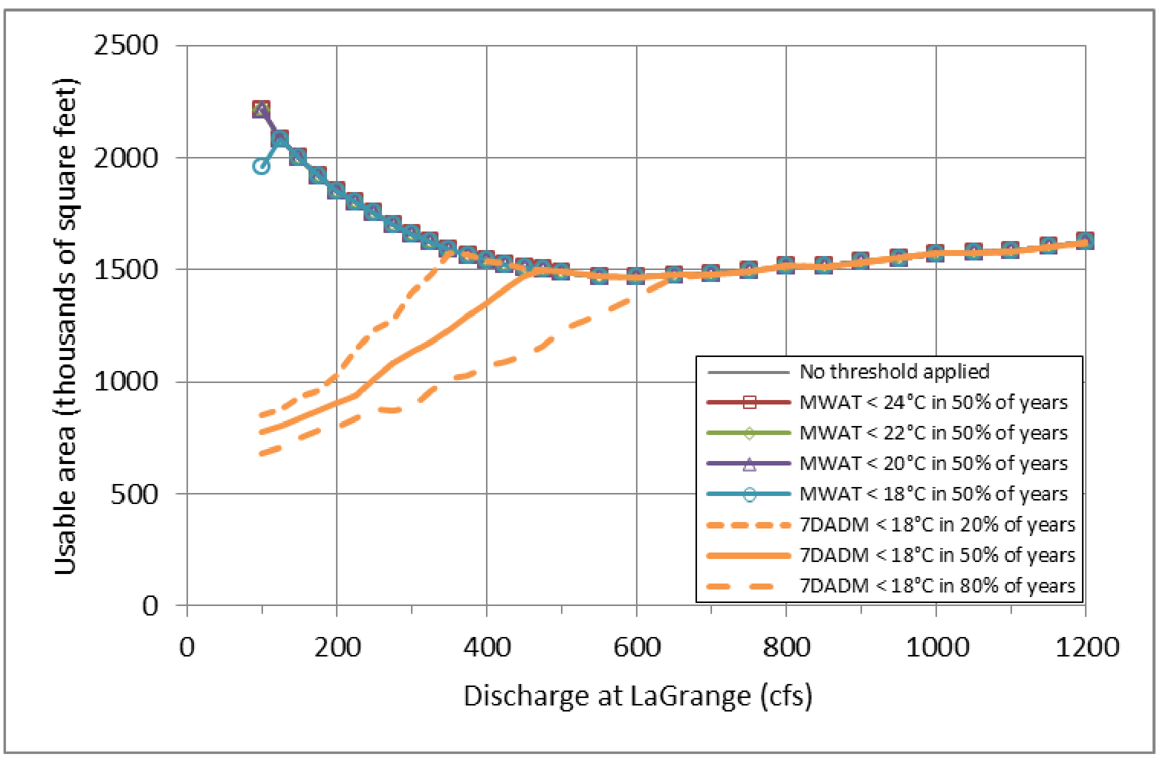

Figure D-14. Effective habitat for *O. mykiss* fry in September for habitats in sub-reaches 1-2 (RM 51.9 to RM 43.1) meeting selected temperature thresholds.

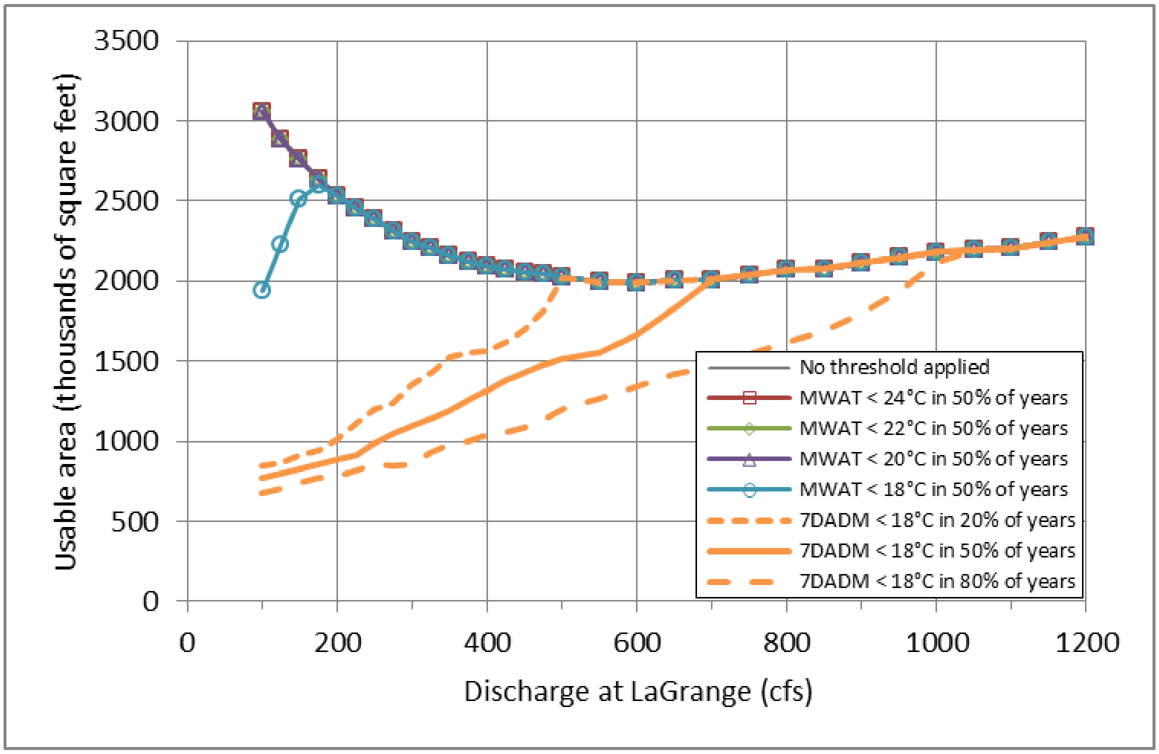

Figure D-15. Effective habitat for *O. mykiss* fry in September for habitats in sub-reaches 1-3 (RM 51.9 to RM 39.5) meeting selected temperature thresholds.

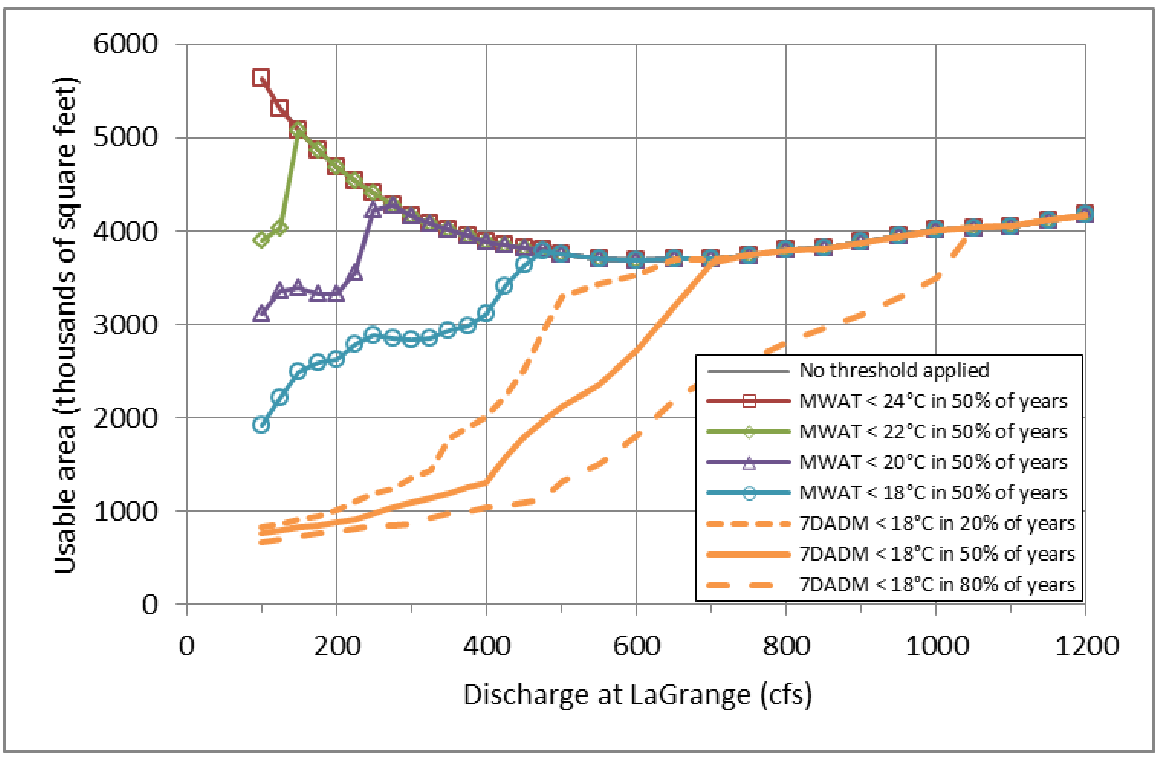

Figure D-16. Effective habitat for *O. mykiss* fry in September for habitats in sub-reaches 1-4 (RM 51.9 to RM 29.1) meeting selected temperature thresholds.

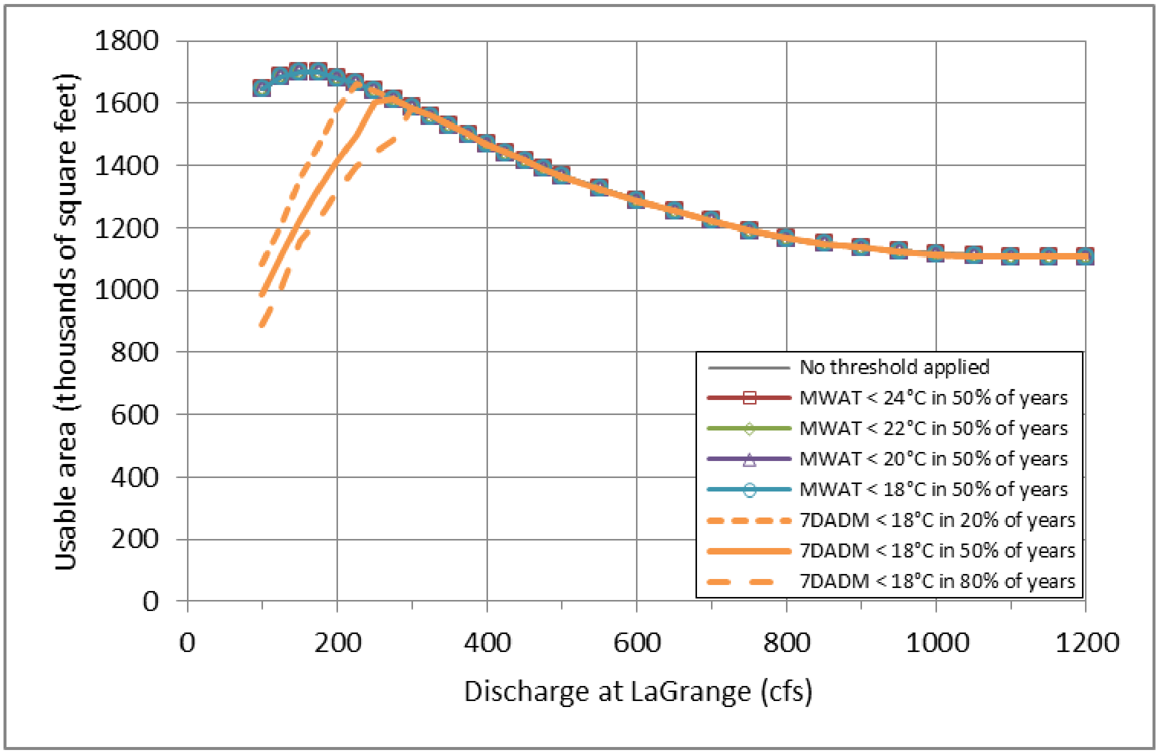

Figure D-17. Effective habitat for *O. mykiss* juvenile in June for habitats in sub-reach 1 (RM 51.9 to RM 46.9) meeting selected temperature thresholds.

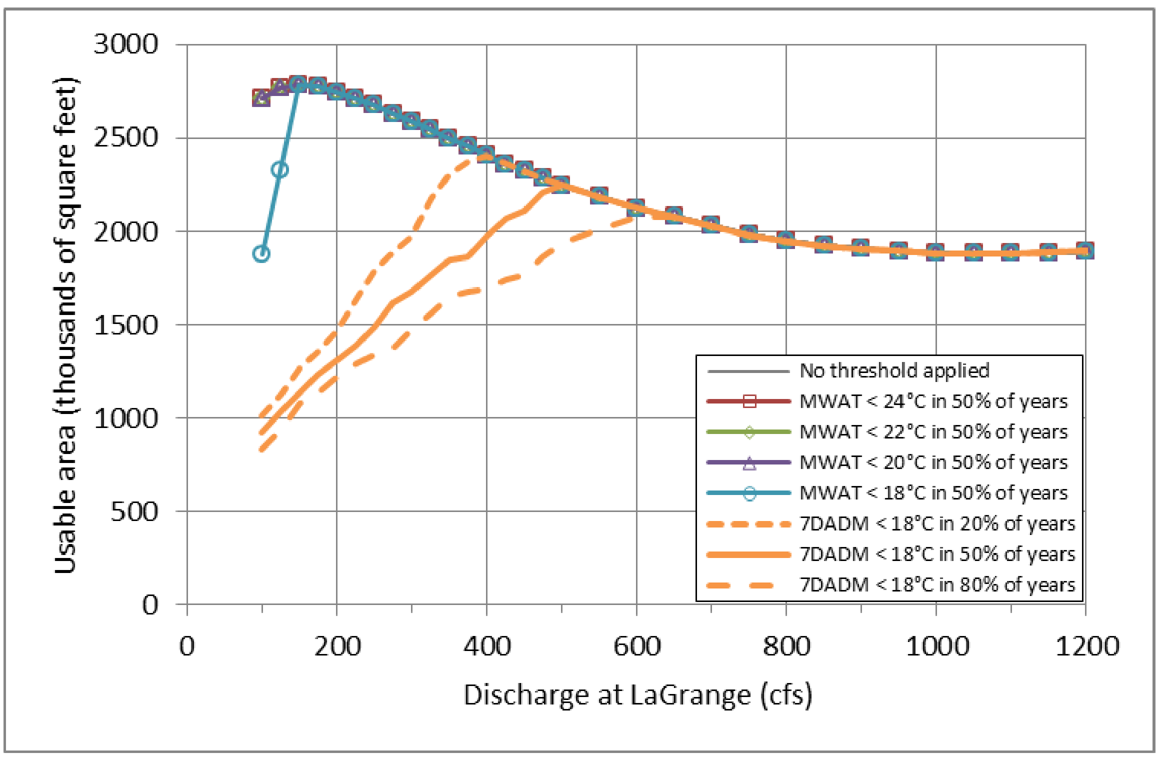

Figure D-18. Effective habitat for *O. mykiss* juvenile in June for habitats in sub-reaches 1-2 (RM 51.9 to RM 43.1) meeting selected temperature thresholds.

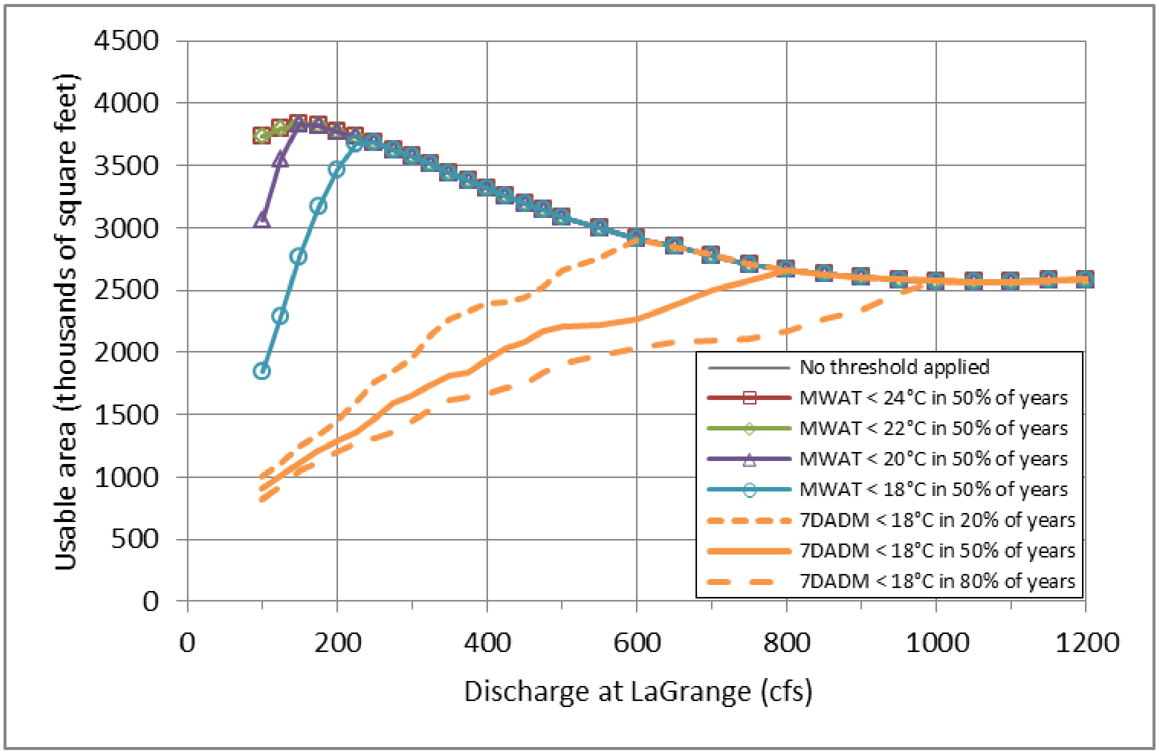

Figure D-19. Effective habitat for *O. mykiss* juvenile in June for habitats in sub-reaches 1-3 (RM 51.9 to RM 39.5) meeting selected temperature thresholds.

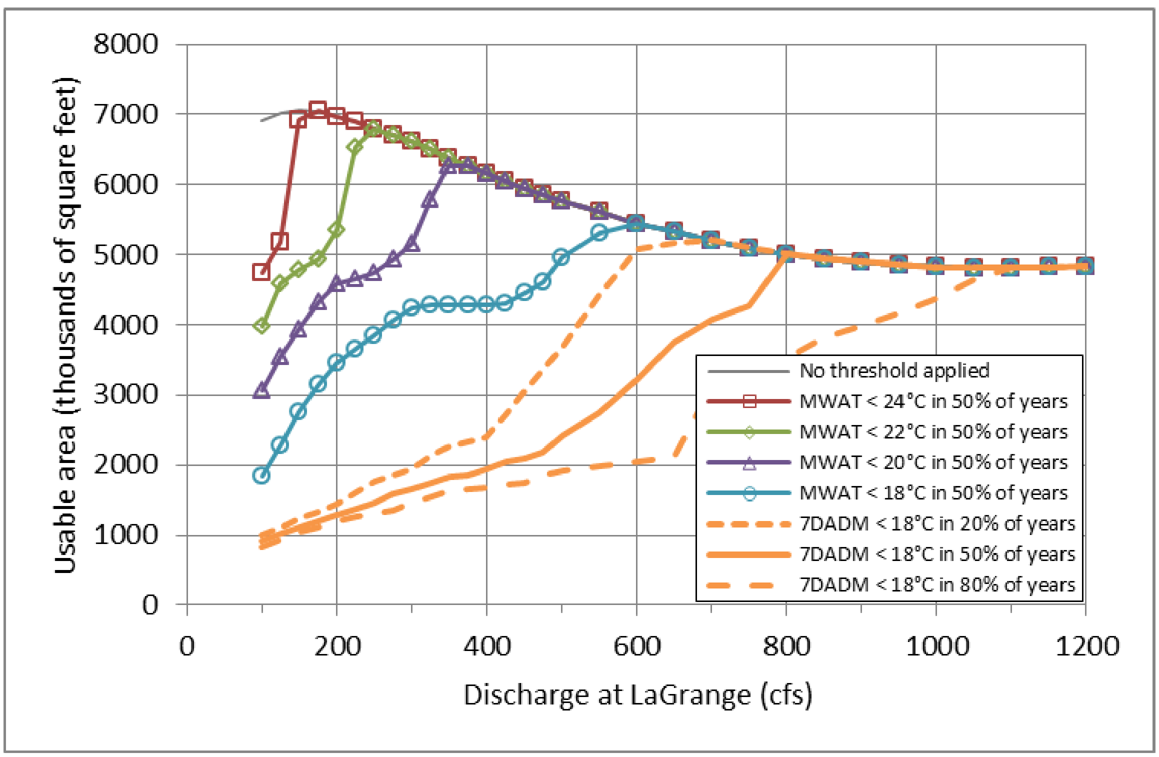

Figure D-20. Effective habitat for *O. mykiss* juvenile in June for habitats in sub-reaches 1-4 (RM 51.9 to RM 29.1) meeting selected temperature thresholds.

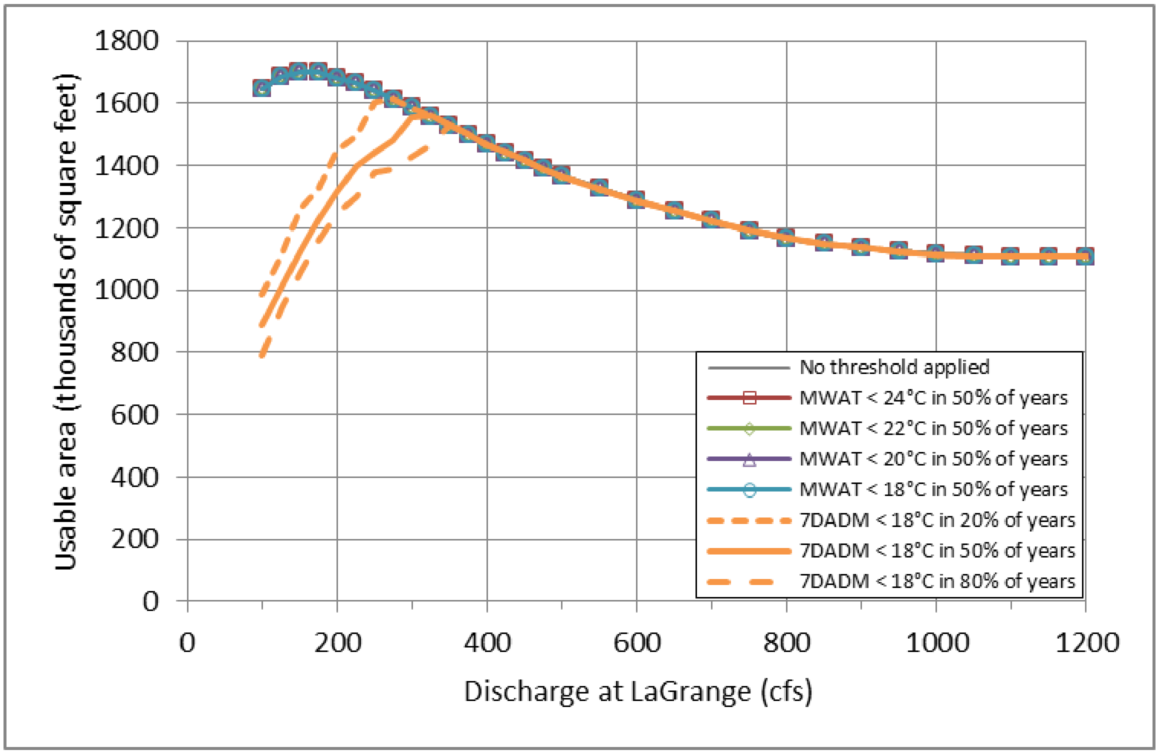

Figure D-21. Effective habitat for *O. mykiss* juvenile in July for habitats in sub-reach 1 (RM 51.9 to RM 46.9) meeting selected temperature thresholds.

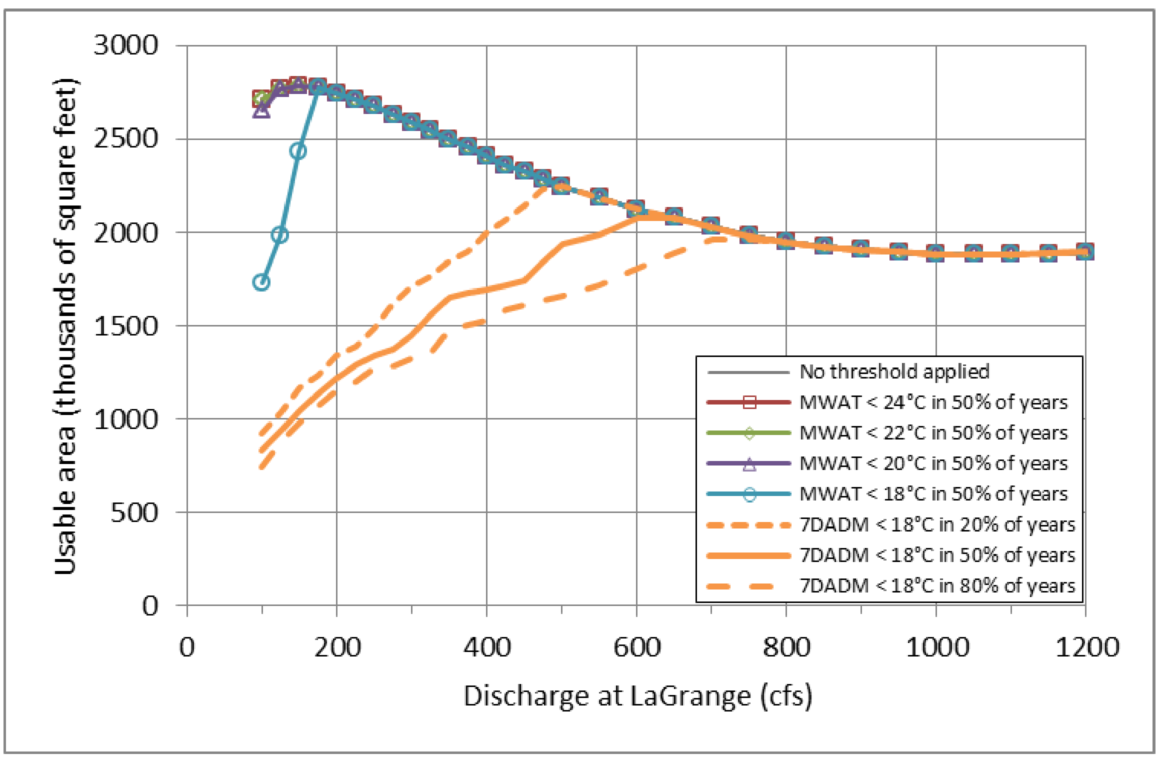

Figure D-22. Effective habitat for *O. mykiss* juvenile in July for habitats in sub-reaches 1-2 (RM 51.9 to RM 43.1) meeting selected temperature thresholds.

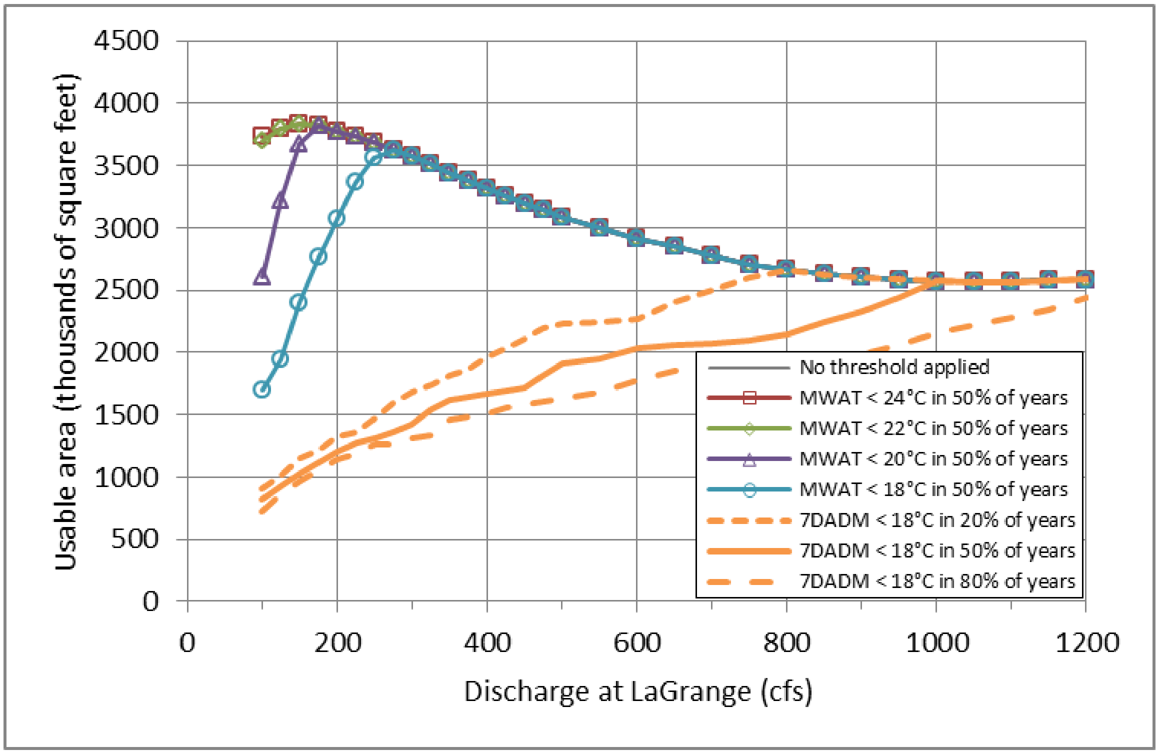

Figure D-23. Effective habitat for *O. mykiss* juvenile in July for habitats in sub-reaches 1-3 (RM 51.9 to RM 39.5) meeting selected temperature thresholds.

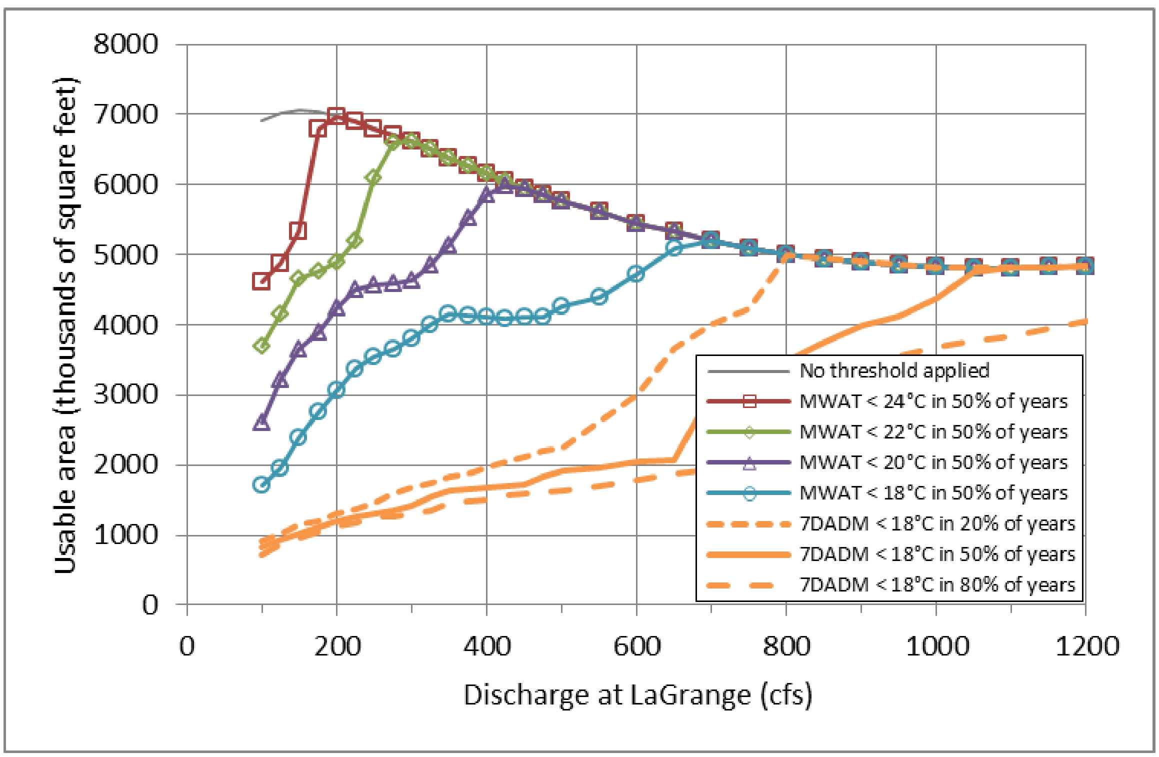

Figure D-24. Effective habitat for *O. mykiss* juvenile in July for habitats in sub-reaches 1-4 (RM 51.9 to RM 29.1) meeting selected temperature thresholds.

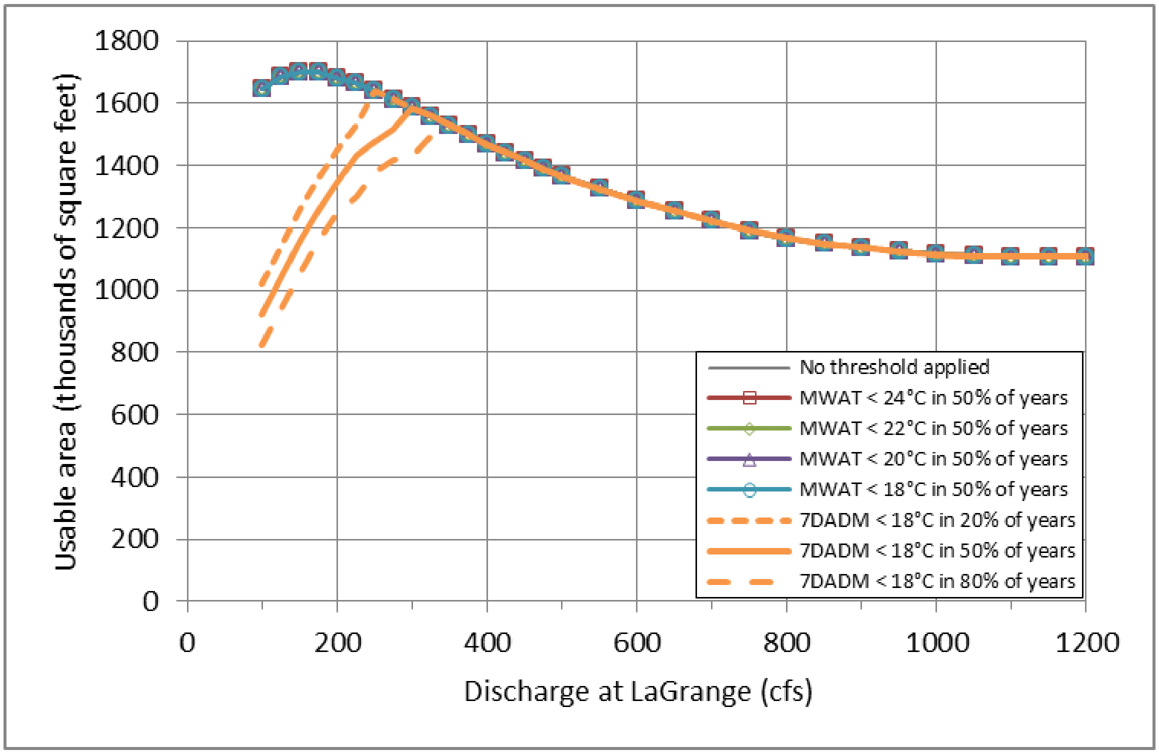

Figure D-25. Effective habitat for *O. mykiss* juvenile in August for habitats in sub-reach 1 (RM 51.9 to RM 46.9) meeting selected temperature thresholds.

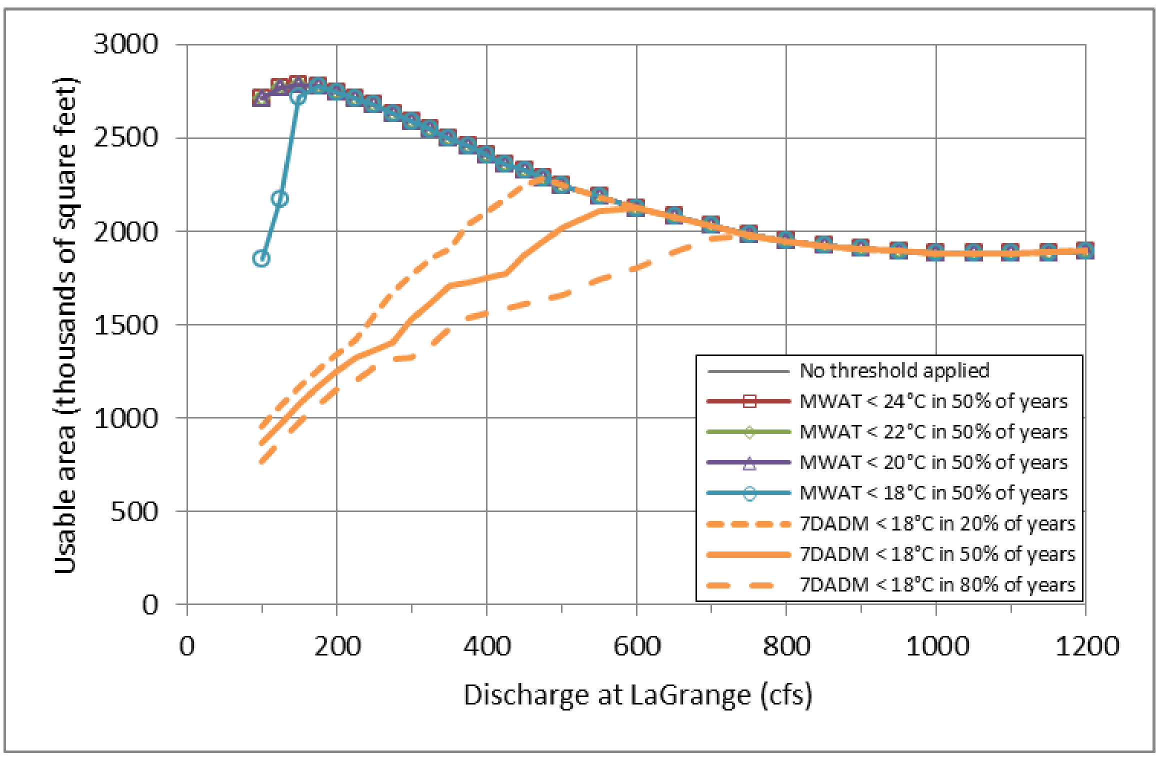

Figure D-26. Effective habitat for *O. mykiss* juvenile in August for habitats in sub-reaches 1-2 (RM 51.9 to RM 43.1) meeting selected temperature thresholds.

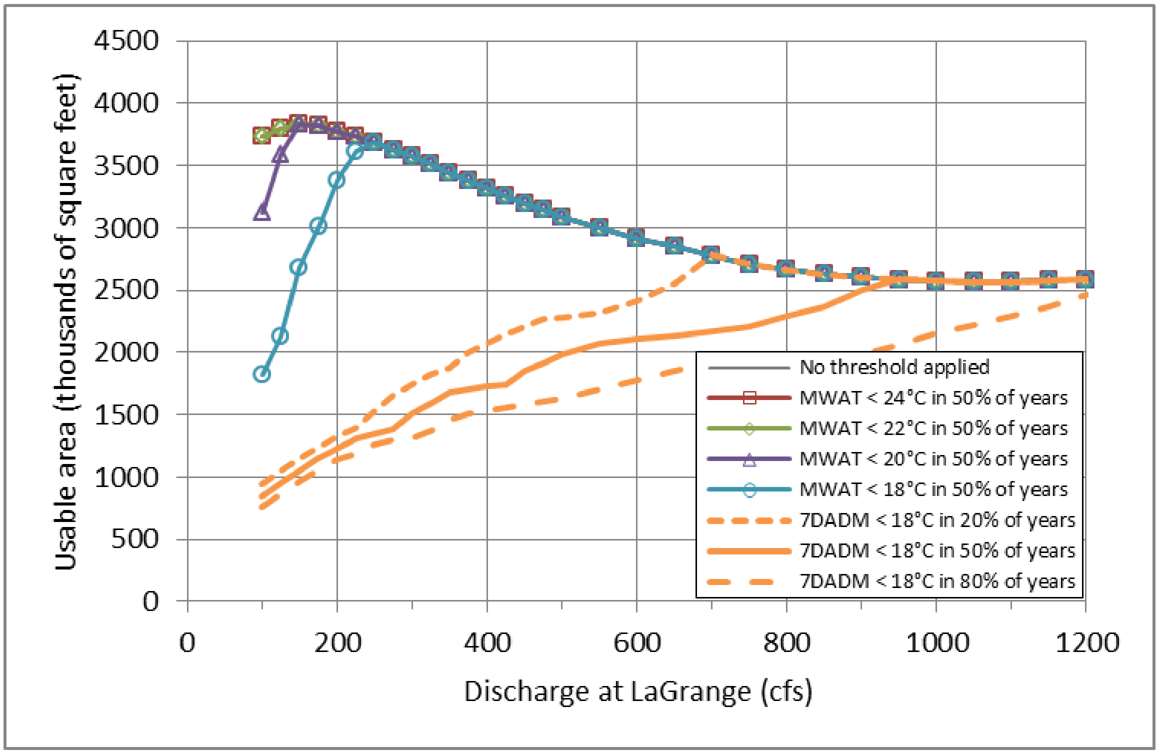

Figure D-27. Effective habitat for *O. mykiss* juvenile in August for habitats in sub-reaches 1-3 (RM 51.9 to RM 39.5) meeting selected temperature thresholds.

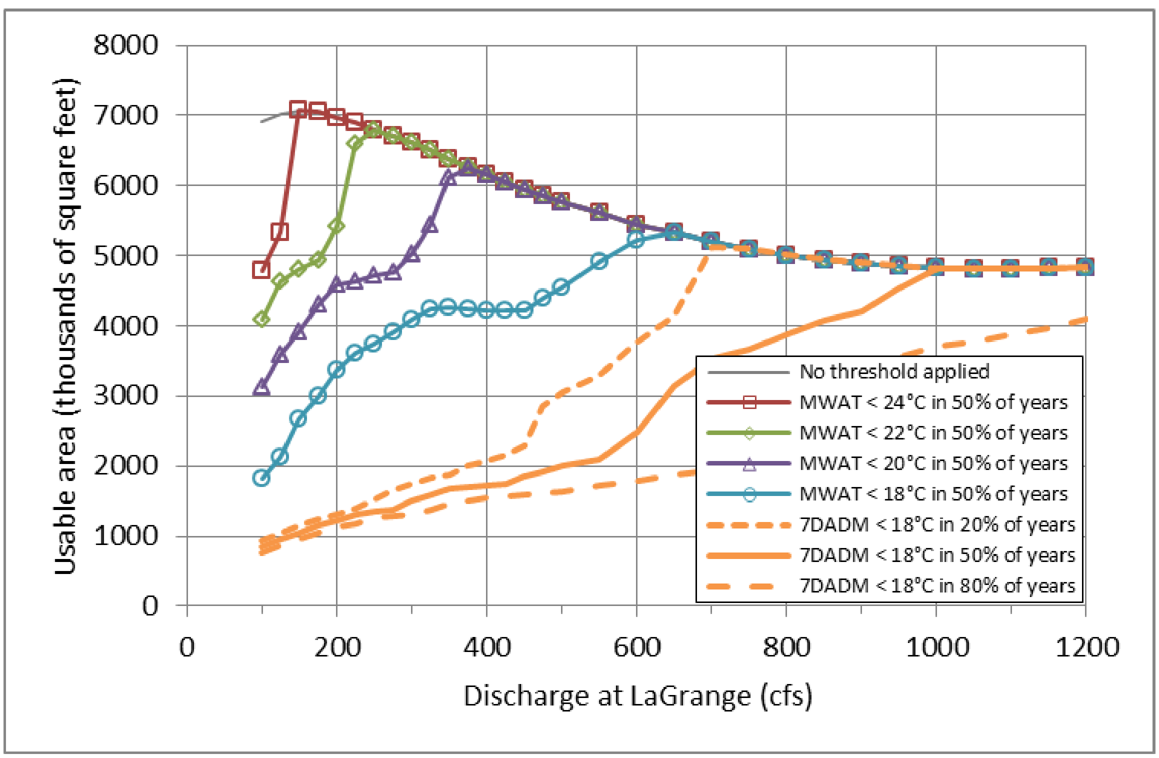

Figure D-28. Effective habitat for *O. mykiss* juvenile in August for habitats in sub-reaches 1-4 (RM 51.9 to RM 29.1) meeting selected temperature thresholds.

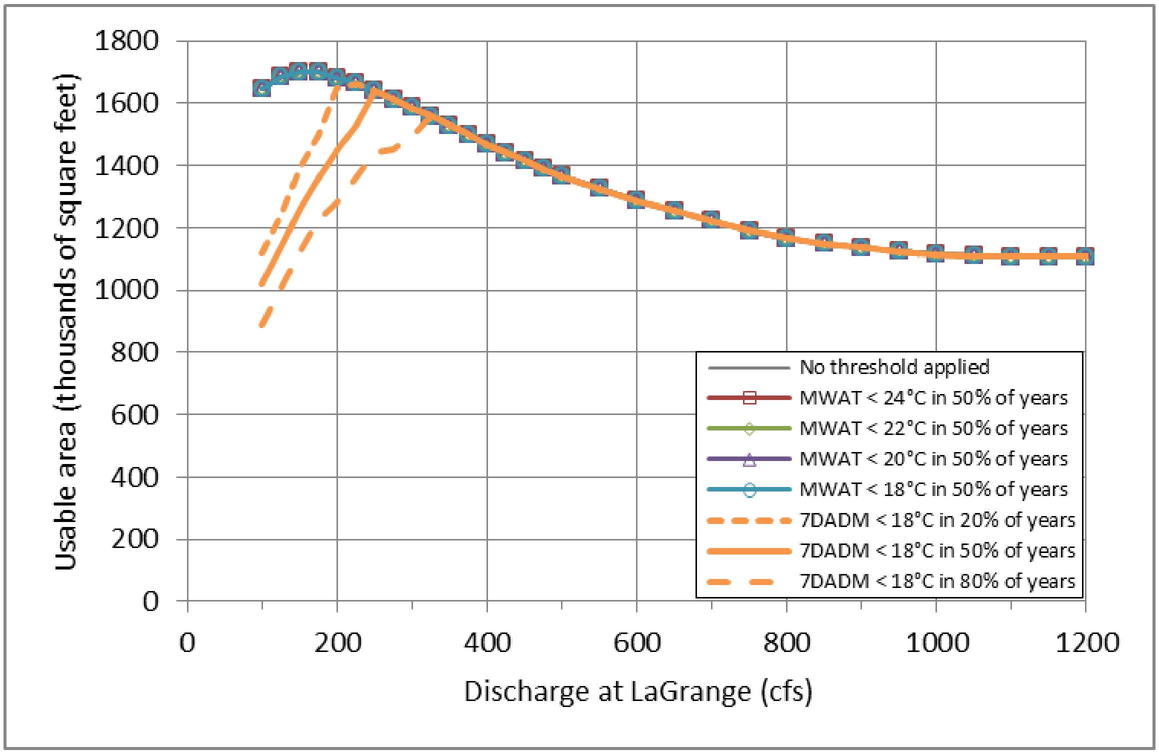

Figure D-29. Effective habitat for *O. mykiss* juvenile in September for habitats in sub-reach 1 (RM 51.9 to RM 46.9) meeting selected temperature thresholds.

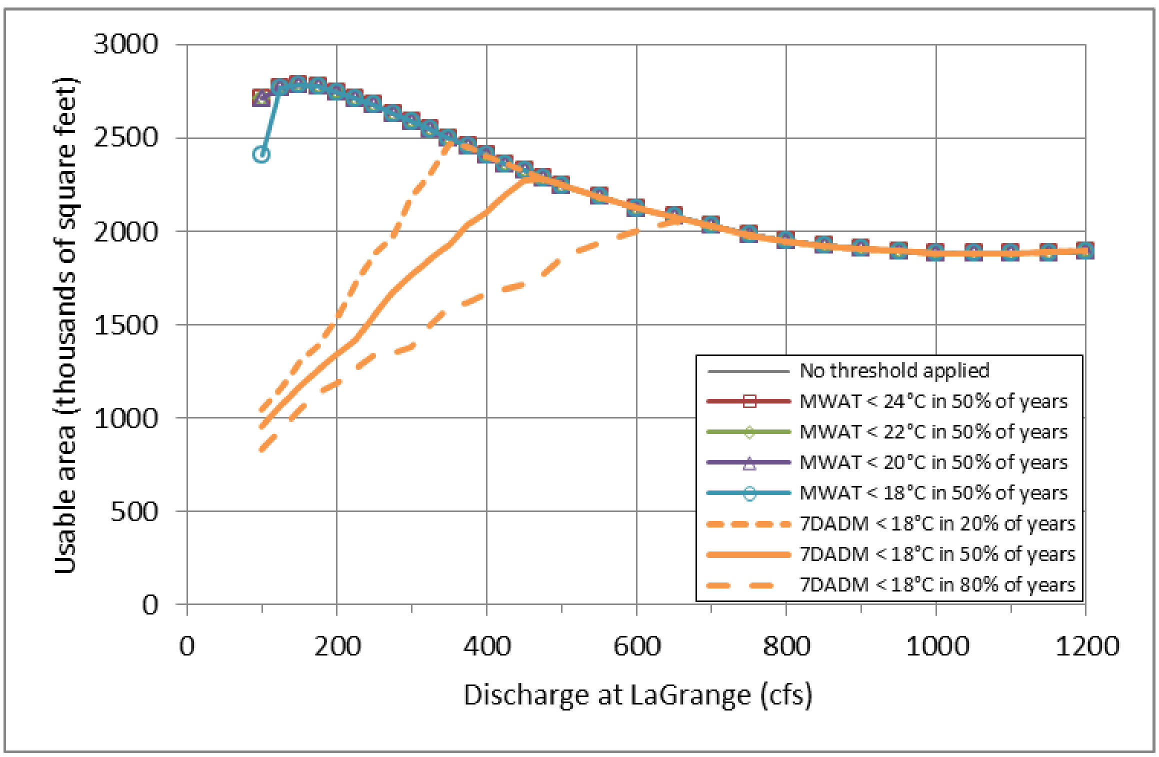

Figure D-30. Effective habitat for *O. mykiss* juvenile in September for habitats in sub-reaches 1-2 (RM 51.9 to RM 43.1) meeting selected temperature thresholds.

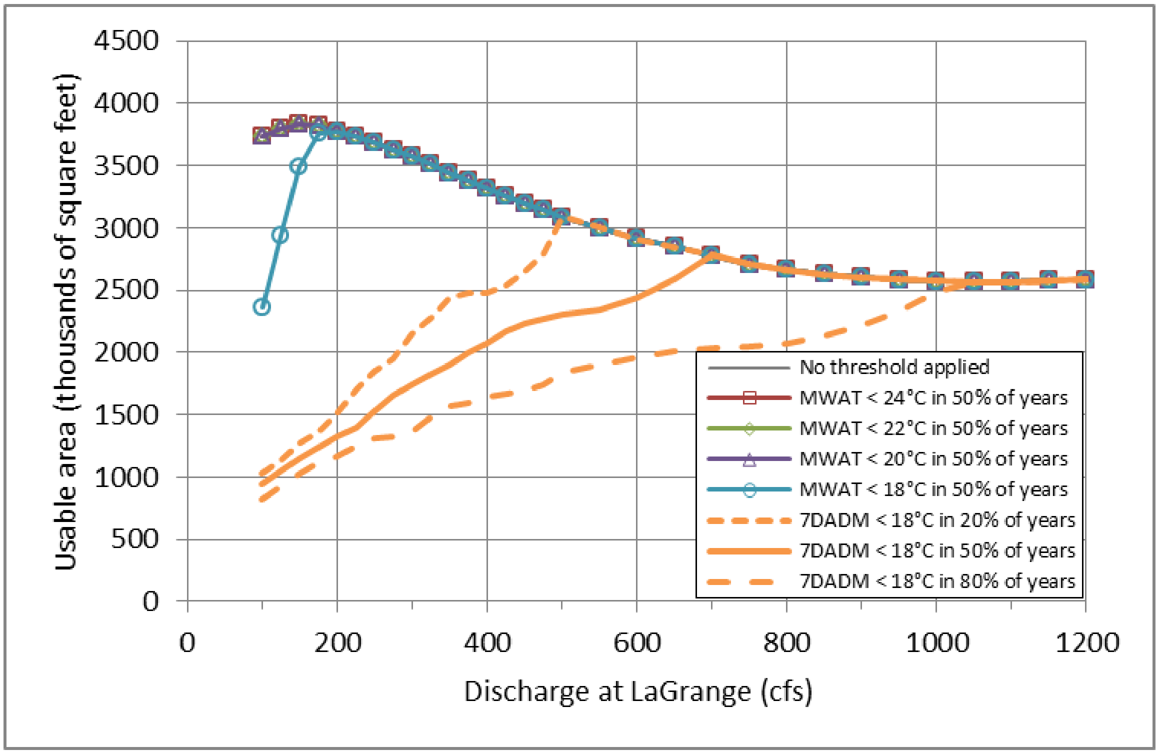

Figure D-31. Effective habitat for *O. mykiss* juvenile in September for habitats in sub-reaches 1-3 (RM 51.9 to RM 39.5) meeting selected temperature thresholds.

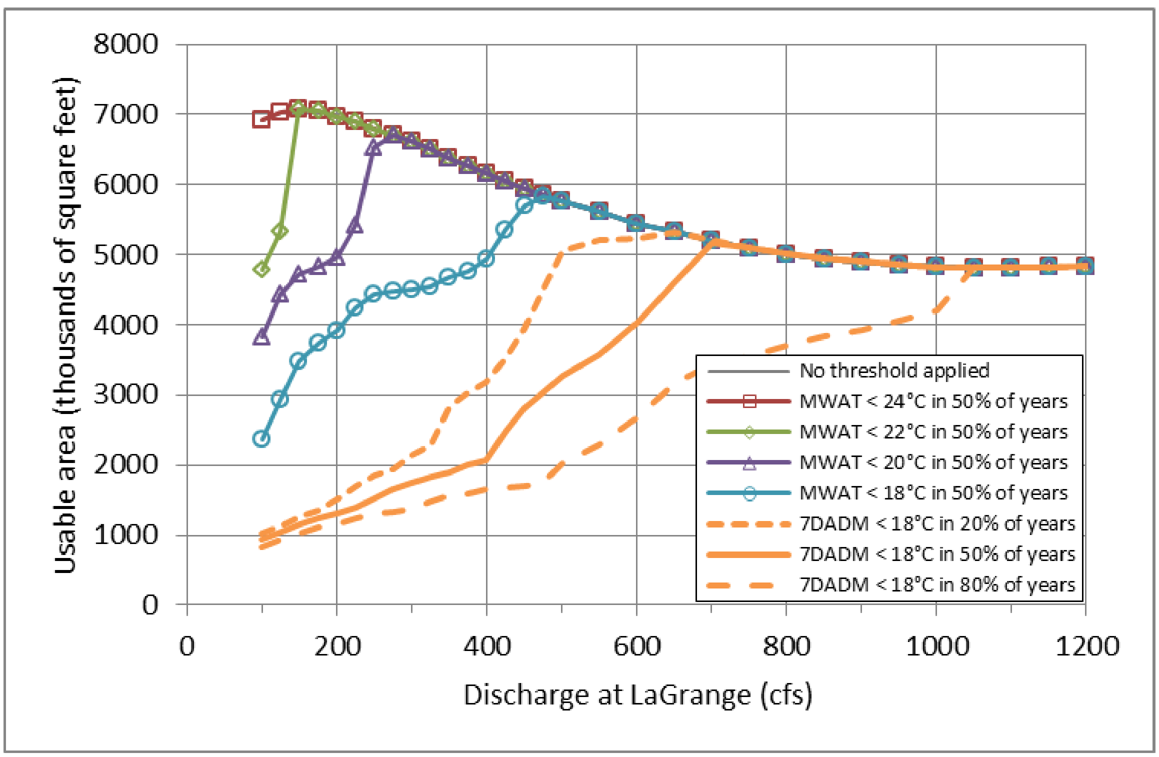

Figure D-32. Effective habitat for *O. mykiss* juvenile in September for habitats in sub-reaches 1-4 (RM 51.9 to RM 29.1) meeting selected temperature thresholds.

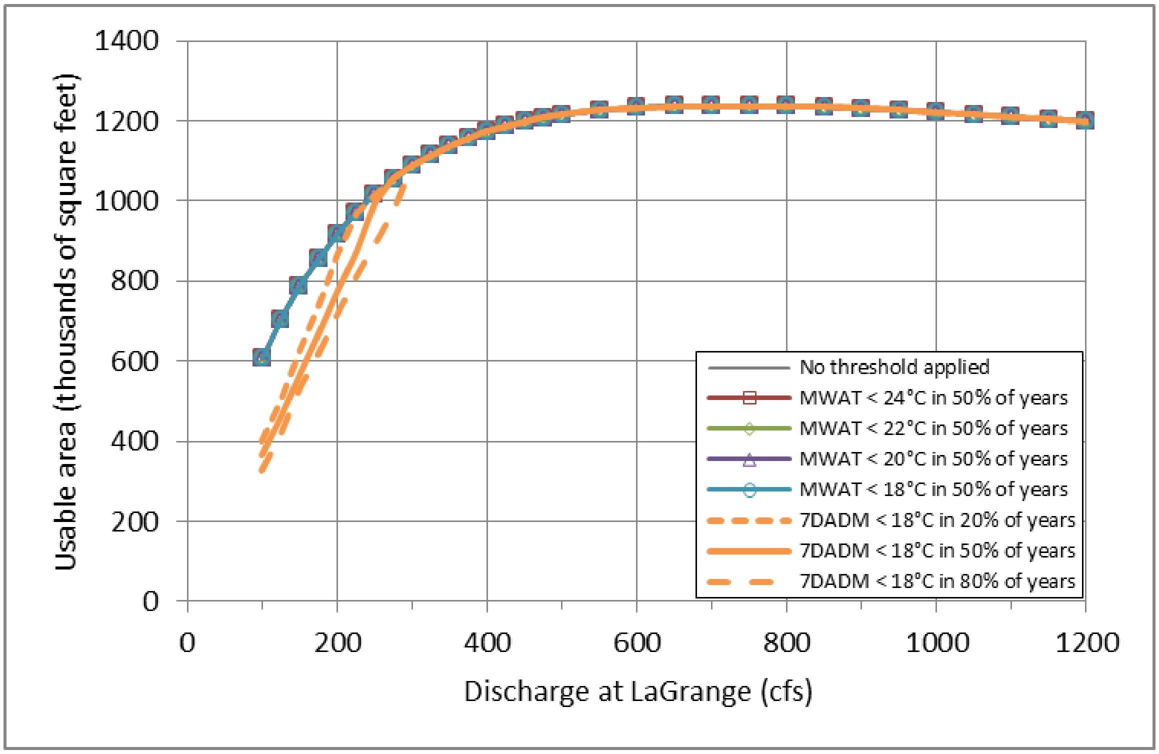

Figure D-33. Effective habitat for *O. mykiss* adult in June for habitats in sub-reach 1 (RM 51.9 to RM 46.9) meeting selected temperature thresholds.

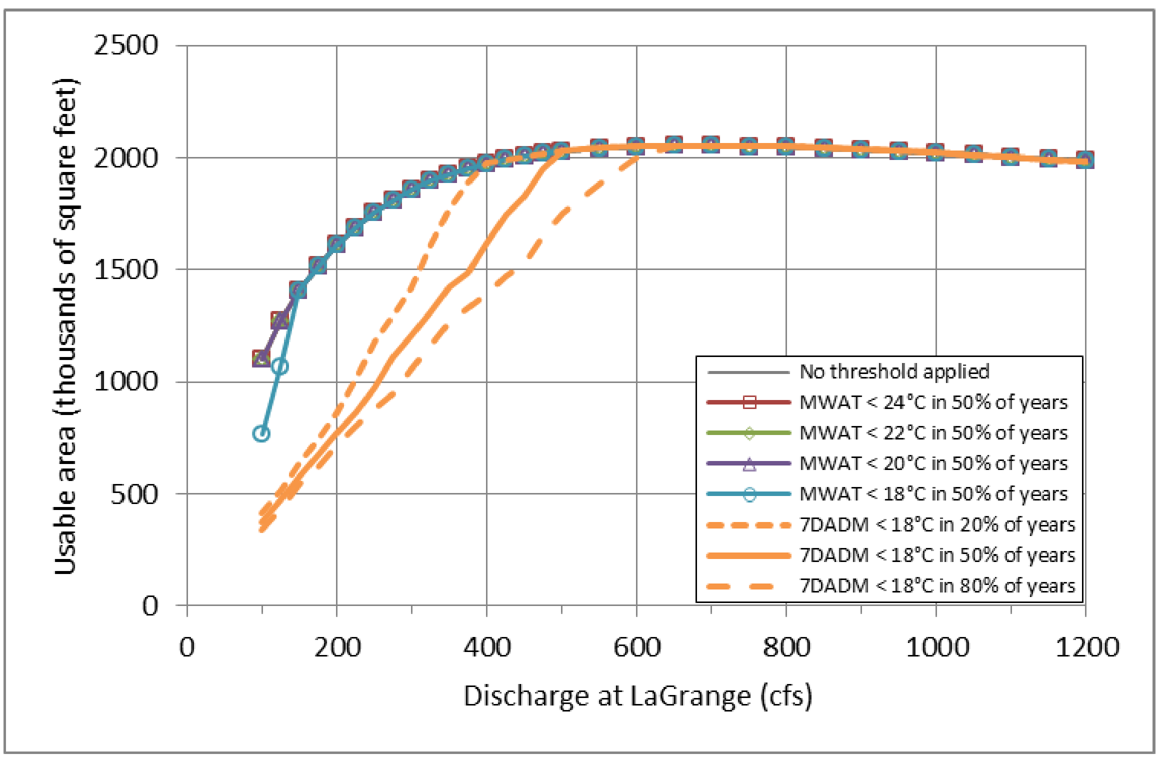

Figure D-34. Effective habitat for *O. mykiss* adult in June for habitats in sub-reaches 1-2 (RM 51.9 to RM 43.1) meeting selected temperature thresholds.

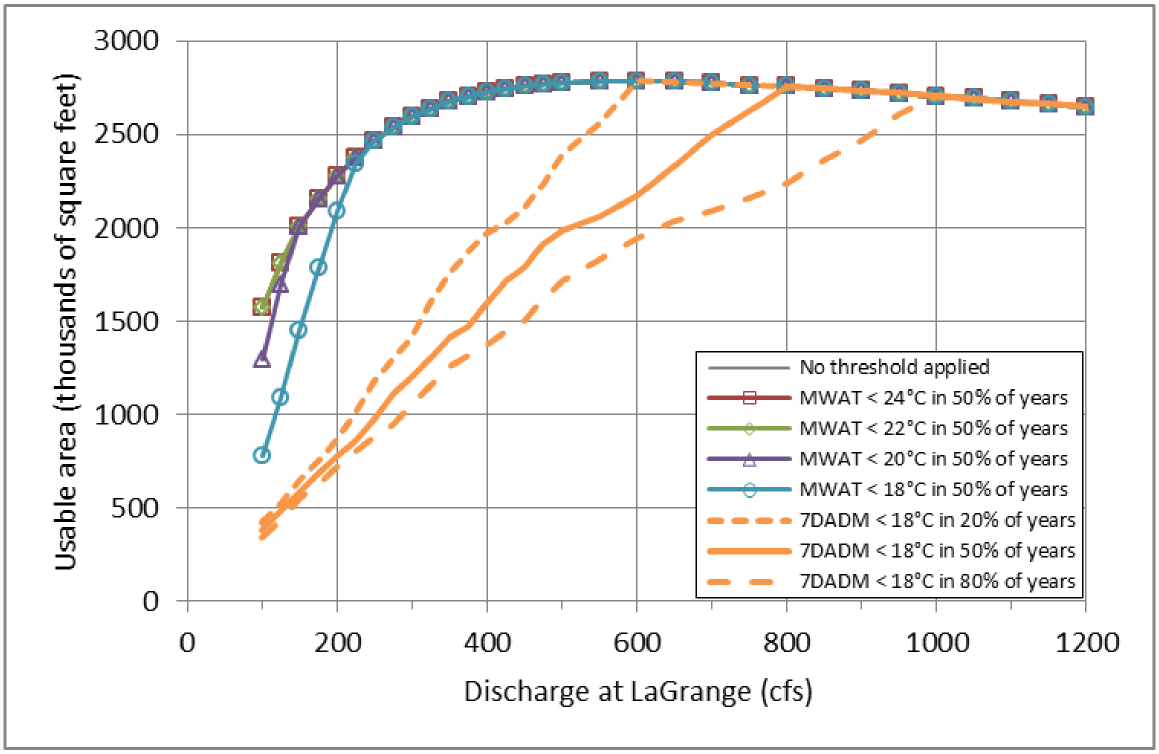

Figure D-35. Effective habitat for *O. mykiss* adult in June for habitats in sub-reaches 1-3 (RM 51.9 to RM 39.5) meeting selected temperature thresholds.

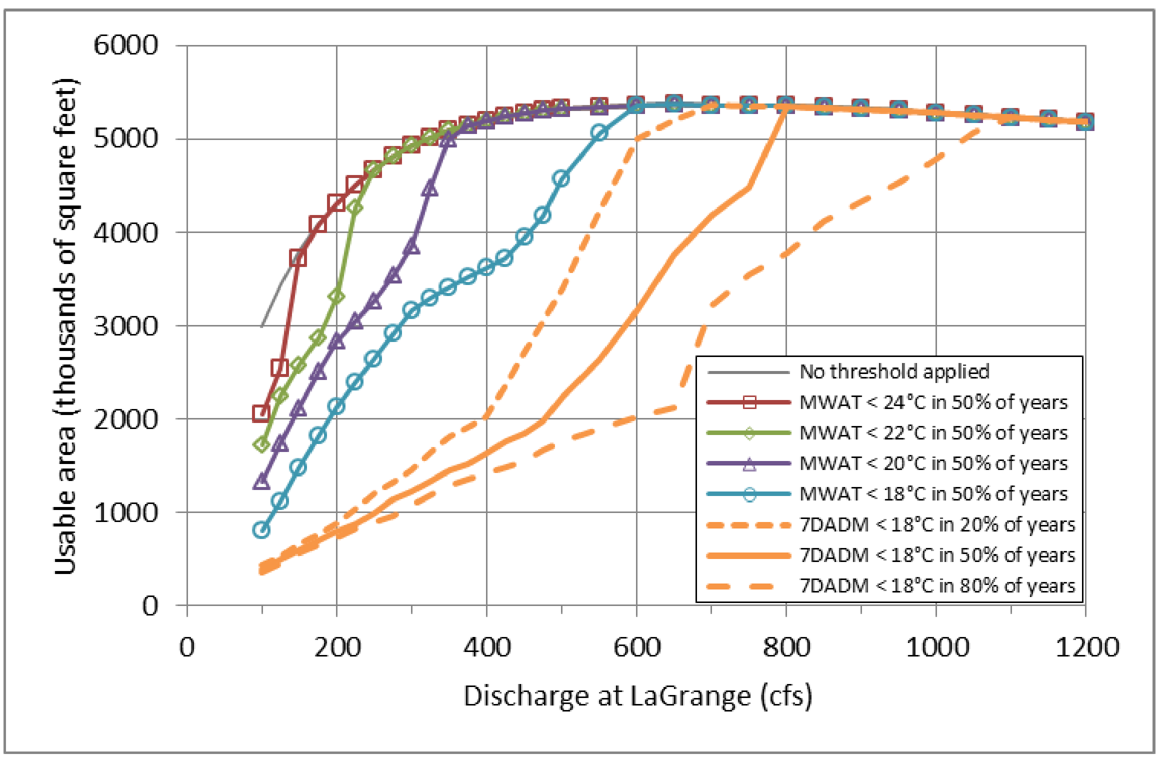

Figure D-36. Effective habitat for *O. mykiss* adult in June for habitats in sub-reaches 1-4 (RM 51.9 to RM 29.1) meeting selected temperature thresholds.

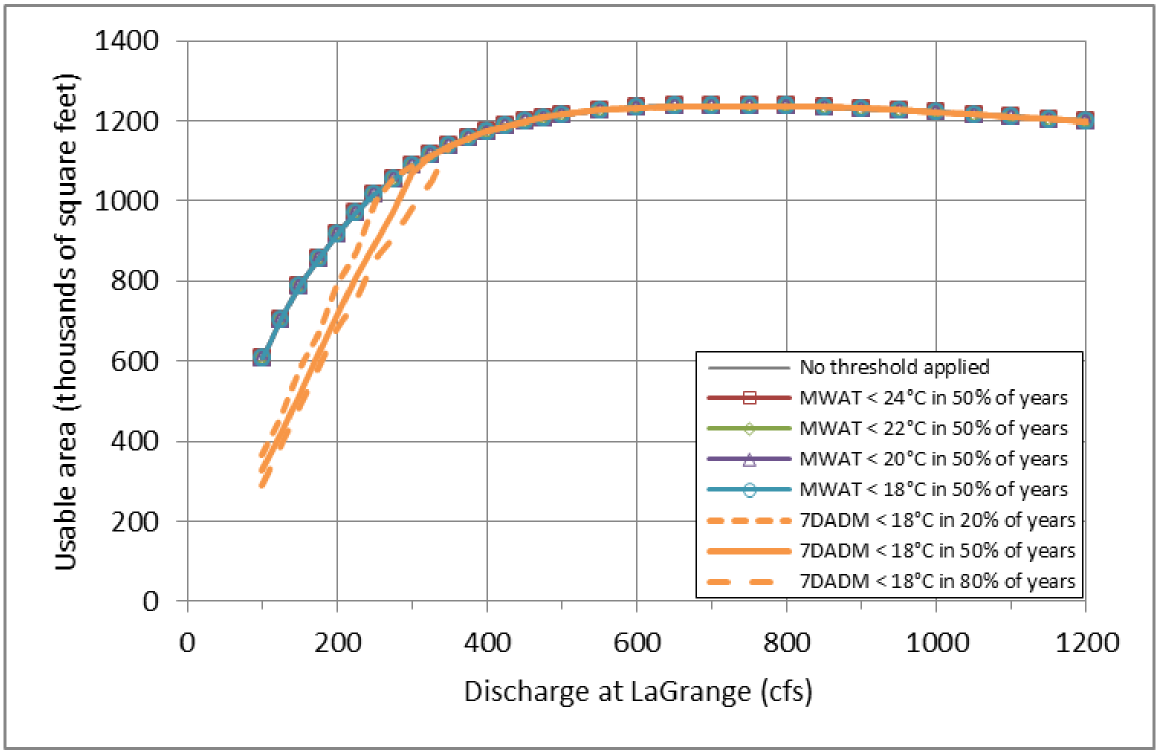

Figure D-37. Effective habitat for *O. mykiss* adult in July for habitats in sub-reach 1 (RM 51.9 to RM 46.9) meeting selected temperature thresholds.

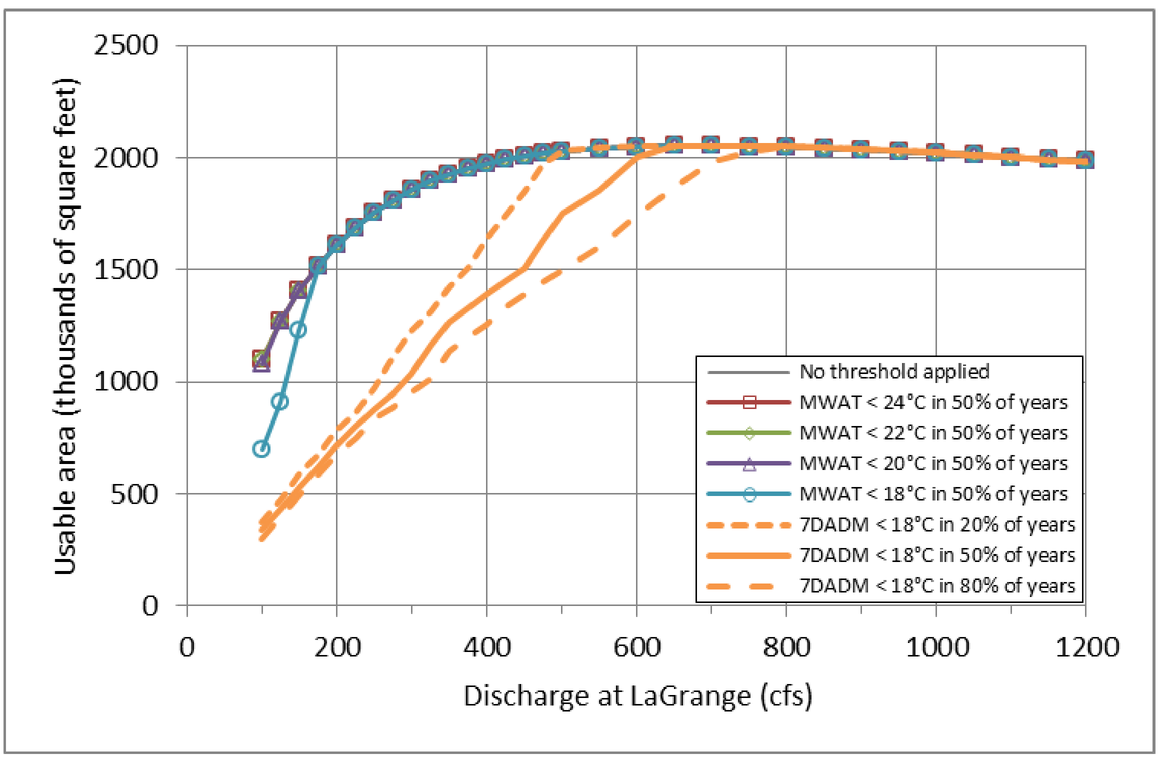

Figure D-38. Effective habitat for *O. mykiss* adult in July for habitats in sub-reaches 1-2 (RM 51.9 to RM 43.1) meeting selected temperature thresholds.

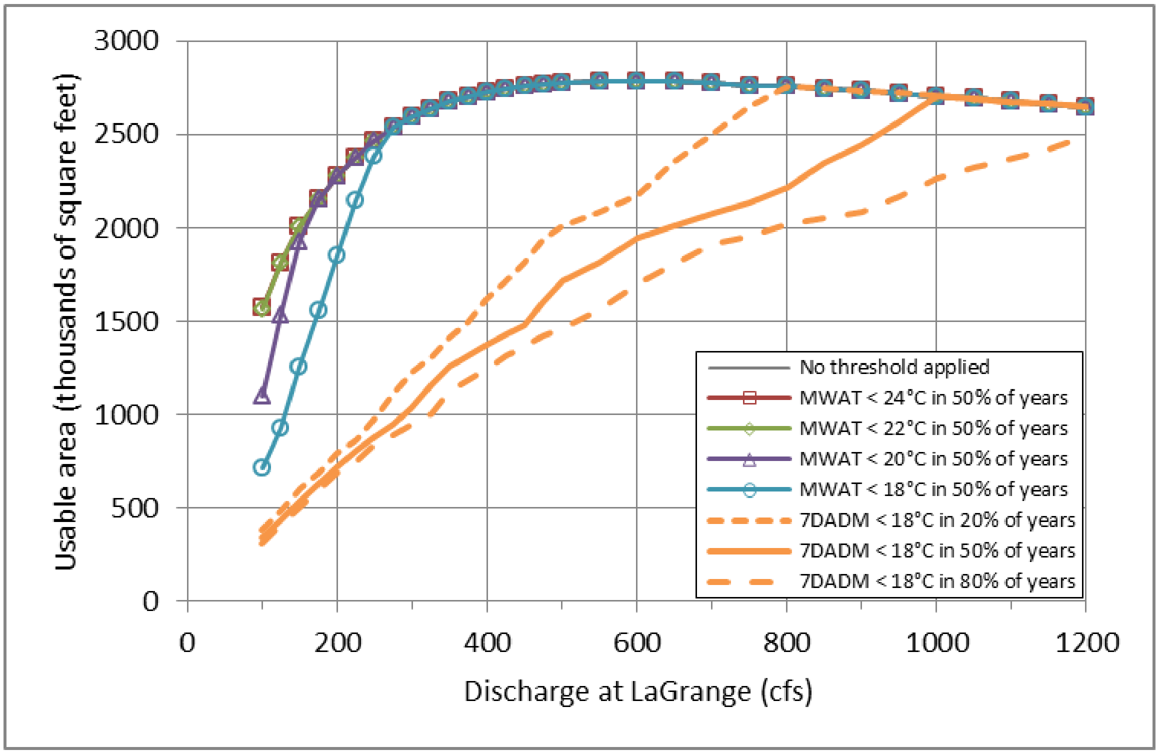

Figure D-39. Effective habitat for *O. mykiss* adult in July for habitats in sub-reaches 1-3 (RM 51.9 to RM 39.5) meeting selected temperature thresholds.

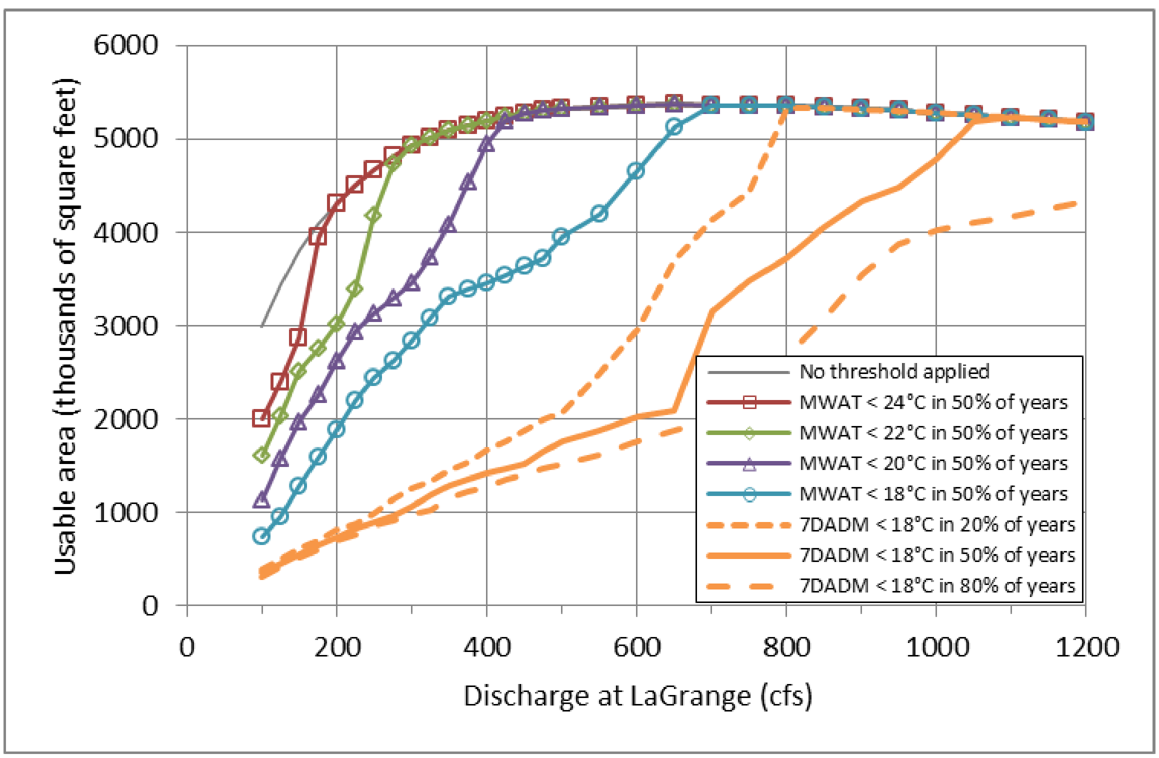

Figure D-40. Effective habitat for *O. mykiss* adult in July for habitats in sub-reaches 1-4 (RM 51.9 to RM 29.1) meeting selected temperature thresholds.

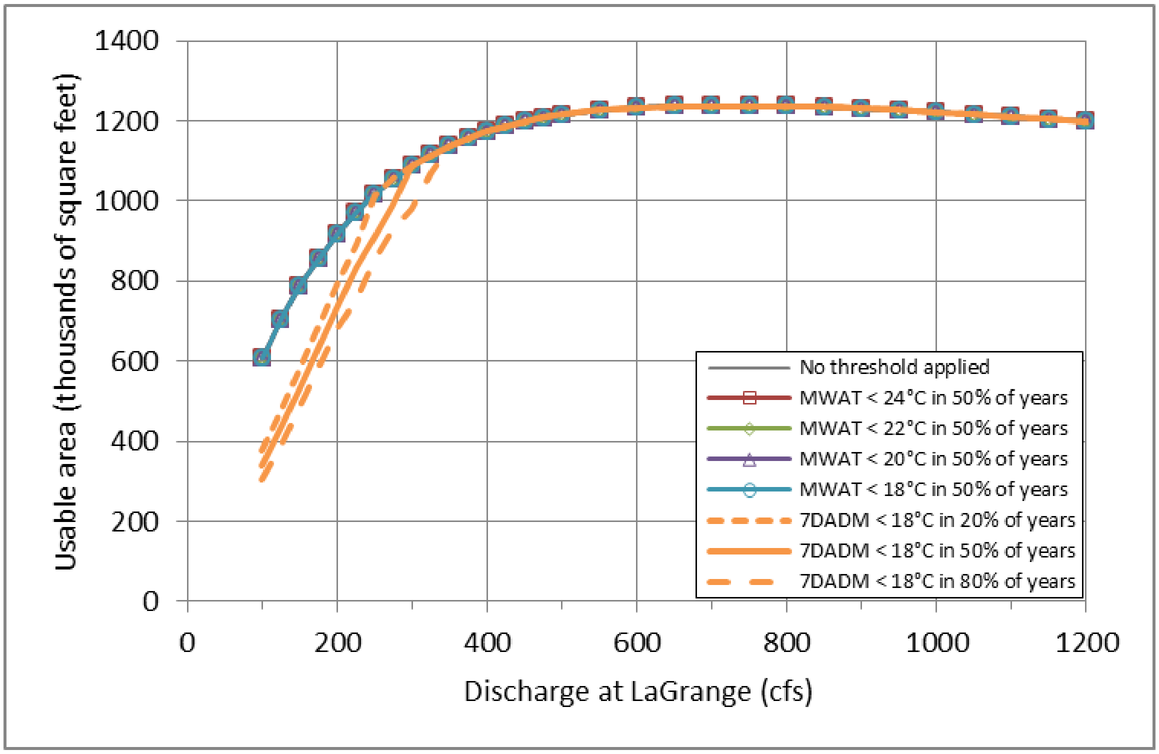

Figure D-41. Effective habitat for *O. mykiss* adult in August for habitats in sub-reach 1 (RM 51.9 to RM 46.9) meeting selected temperature thresholds.

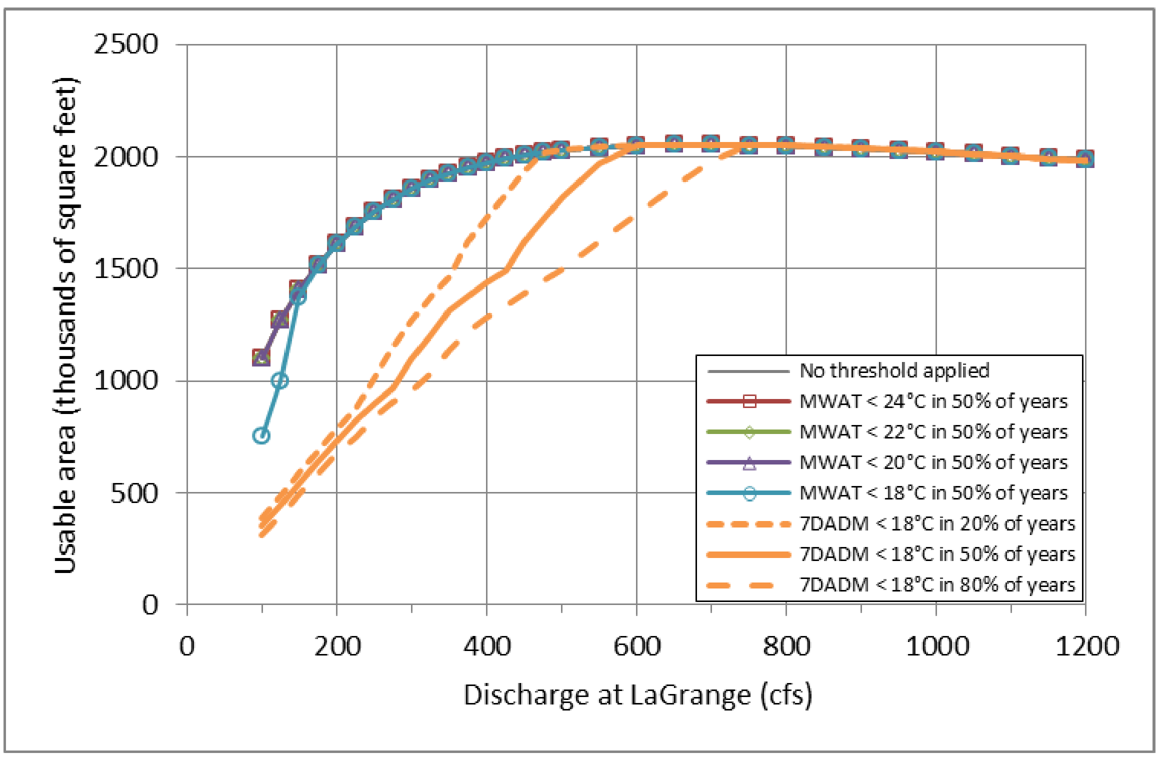

Figure D-42. Effective habitat for *O. mykiss* adult in August for habitats in sub-reaches 1-2 (RM 51.9 to RM 43.1) meeting selected temperature thresholds.

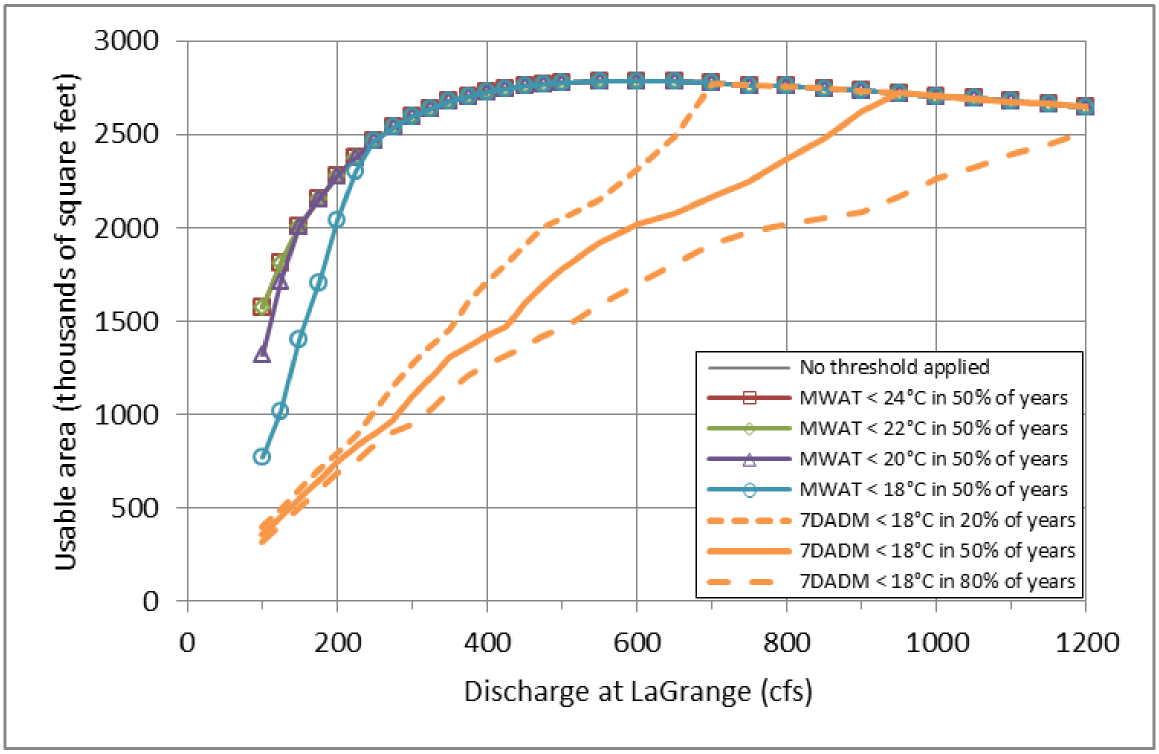

Figure D-43. Effective habitat for *O. mykiss* adult in August for habitats in sub-reaches 1-3 (RM 51.9 to RM 39.5) meeting selected temperature thresholds.

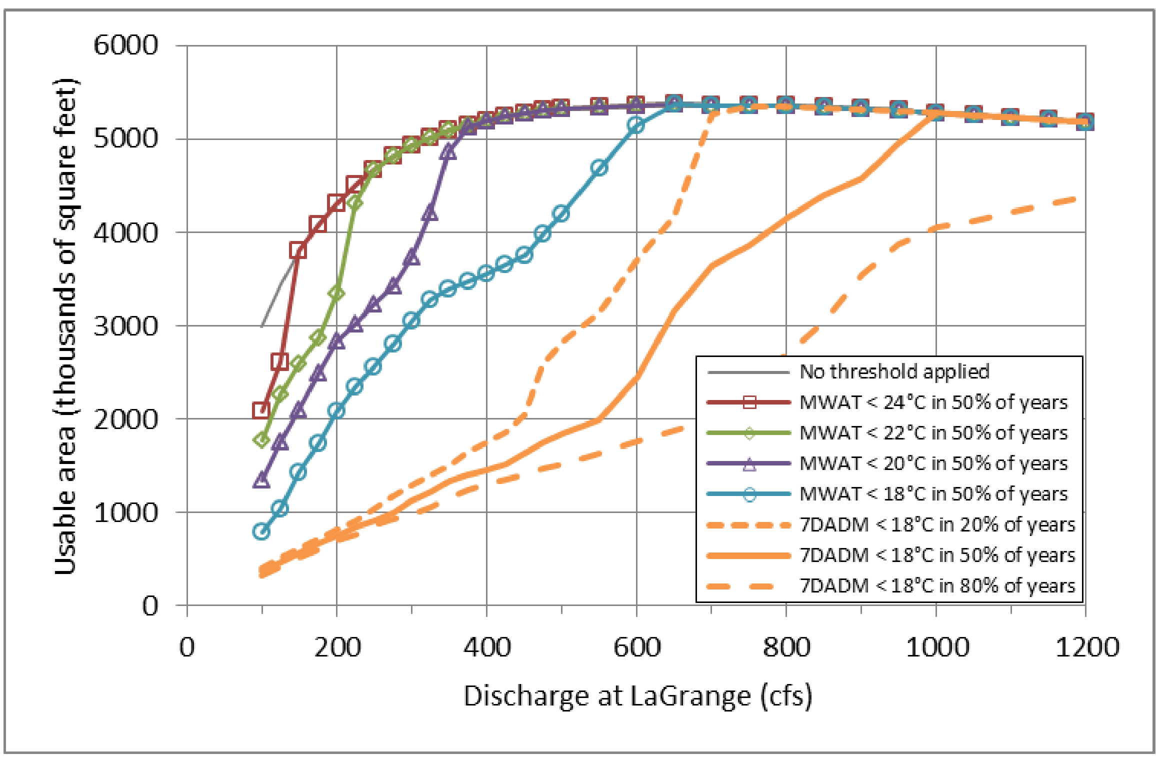

Figure D-44. Effective habitat for *O. mykiss* adult in August for habitats in sub-reaches 1-4 (RM 51.9 to RM 29.1) meeting selected temperature thresholds.

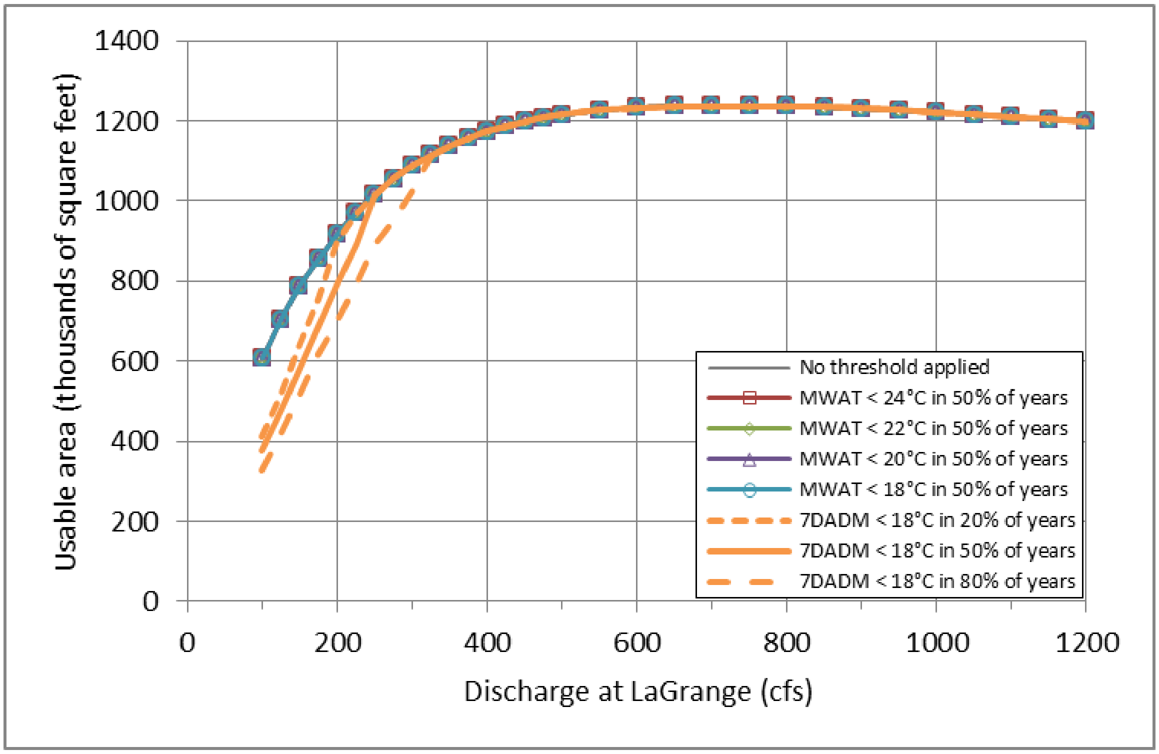

Figure D-45. Effective habitat for *O. mykiss* adult in September for habitats in sub-reach 1 (RM 51.9 to RM 46.9) meeting selected temperature thresholds.

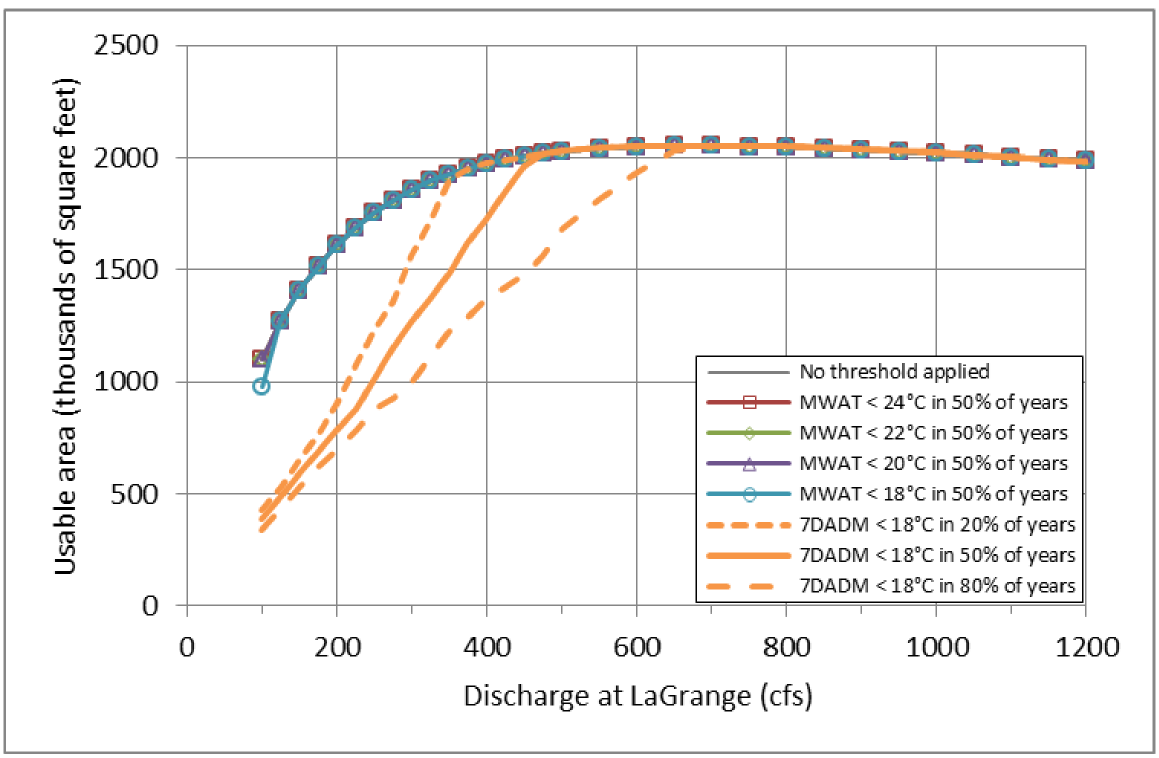

Figure D-46. Effective habitat for *O. mykiss* adult in September for habitats in sub-reaches 1-2 (RM 51.9 to RM 43.1) meeting selected temperature thresholds.

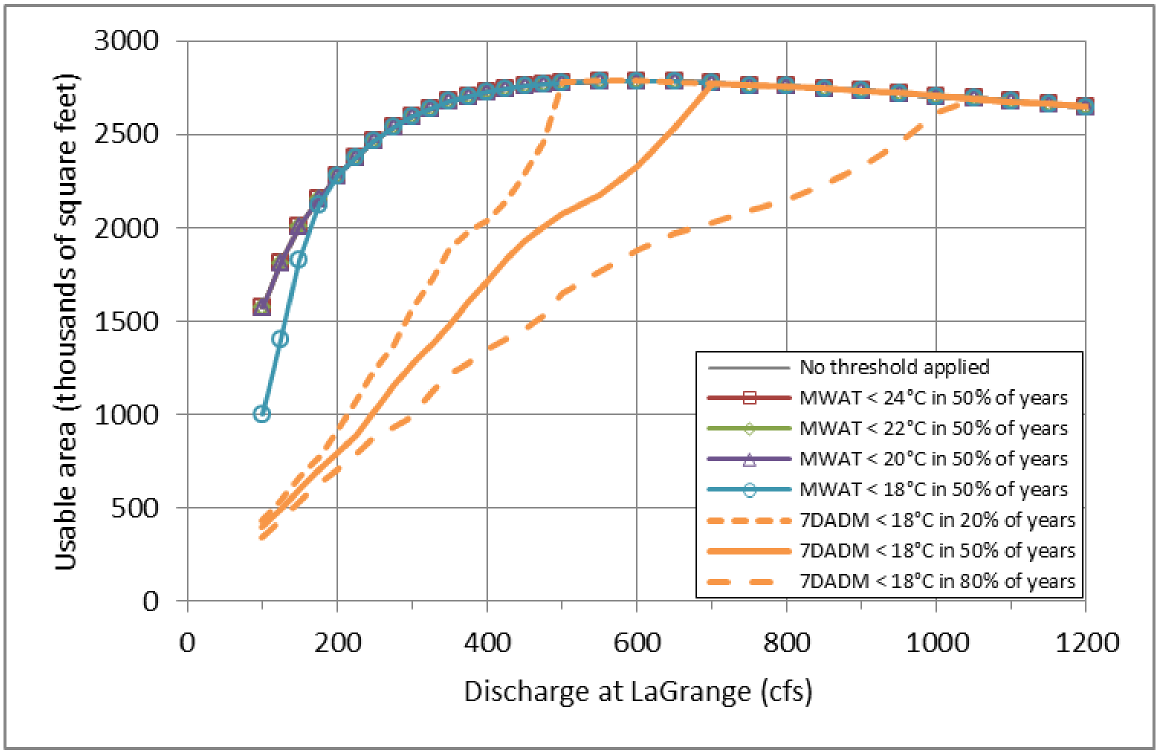

Figure D-47. Effective habitat for *O. mykiss* adult in September for habitats in sub-reaches 1-3 (RM 51.9 to RM 39.5) meeting selected temperature thresholds.

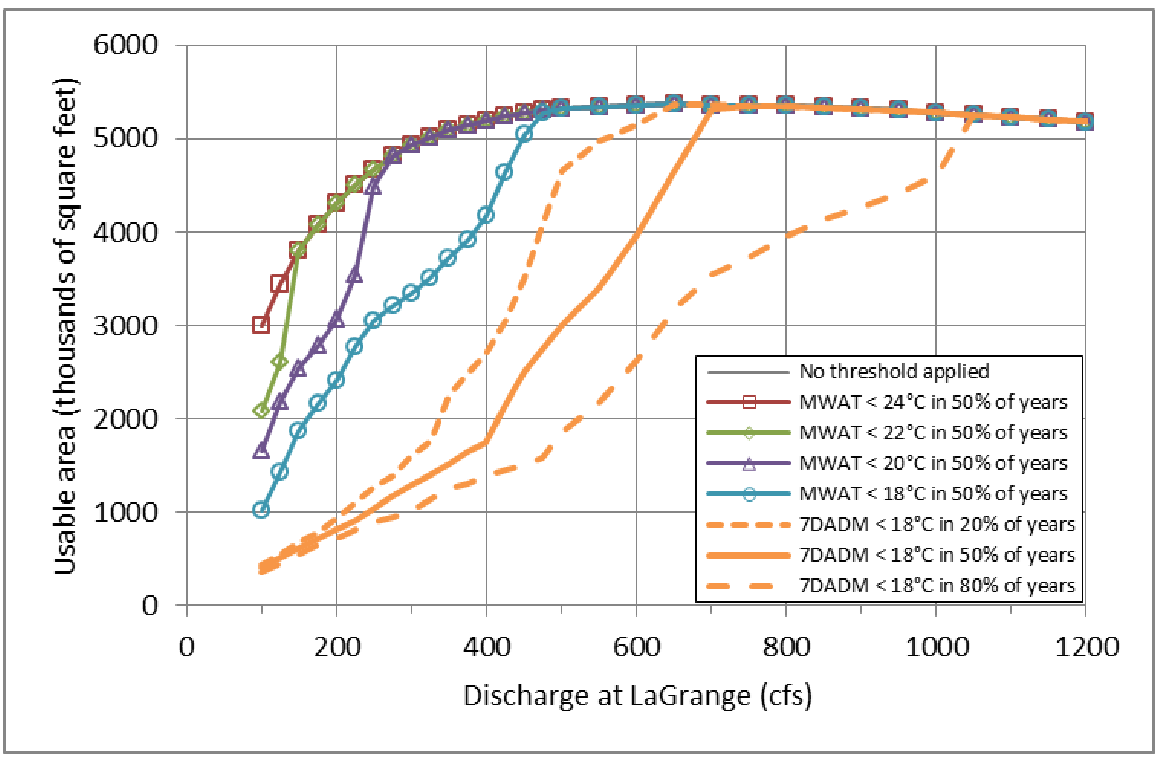

Figure D-48. Effective habitat for *O. mykiss* adult in September for habitats in sub-reaches 1-4 (RM 51.9 to RM 29.1) meeting selected temperature thresholds.