APPENDIX E

Development of Policy Element Alternatives Defining A Range of Protective Levels of Minimum Bypass Flow for Application at the Regional Scale: Upper MBF and Lower MBF Alternatives

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APPENDIX E

DEVELOPMENT OF POLICY ELEMENT ALTERNATIVES DEFINING A RANGE OF PROTECTIVE LEVELS OF MINIMUM BYPASS FLOW FOR APPLICATION AT THE REGIONAL SCALE: UPPER MBF AND LOWER MBF ALTERNATIVES

The term 'minimum bypass flow' (MBF) is an instream flow quantity that is designed to protect downstream fish and aquatic biota. In the DFG-NMFS (2002) Draft Guidelines, water cannot be diverted when natural stream flows are at or below the MBF level. During scoping and as part of analysis completed by other parties, several alternative levels of MBF have been proposed for use in the Policy to protect fish habitat, including the DFG-NMFS (2002) Draft Guidelines February median daily flow (MBF1) and the MTTU (2000) 10% exceedance flow (MBF2) proposals. The extent to which the proposed levels of MBF may or may not be protective at the regional scale was evaluated using a limited set of habitat-flow data from a few sites. However, since the Policy is to be applied at the regional scale, results from a small number of sites may not be representative of habitat-flow needs over the entire range of stream types and varied topography found across the Policy area.

This appendix describes the data and analyses used by R2 to develop two additional minimum bypass flow alternatives that define the upper and lower limits of protectiveness for an MBF evaluated at the regional scale. The two alternatives take into consideration the effects of drainage basin size on bypass flow needs. A large amount of data was compiled that represent habitat-flow needs of streams spanning a broad range of physical conditions. Each alternative allows diversion to occur, but provides a different level of protectiveness:

- The first alternative, Upper MBF (MBF3), corresponds to the instream flows at an upper threshold limit (e.g., approximated conceptually by the upper dotted line in Figure D-5, Appendix D). This alternative allows for diversion, but is risk averse and, hence, conservatively protective toward anadromous salmonids.

- The second alternative, Lower MBF (MBF4), corresponds to instream flows at the lower threshold limit of the possible range depicted in Figure D-5, below which there is substantial risk of impacting the sustainability of anadromous salmonid populations. This alternative allows higher water usage and diversions, while still providing some level of protection to anadromous salmonids.

There are three life stages of anadromous salmonids that are directly influenced by a MBF:

- Upstream passage - a minimum instream flow is needed above which adult passage is possible, including within depth-constricted sections of the channel;

- Spawning and incubation – the quantity and quality of spawning habitat is controlled by instream flows that provide suitable depth and velocity combinations over spawning gravels; and
- Juvenile Rearing – the quantity and quality of rearing habitat is controlled by instream flows that provide suitable depths and velocities for rearing, and access to cover and refuge areas during winter months.

The first two of these are the most sensitive with respect to determining a threshold flow below which suitable conditions (passage or spawning) would not be provided. Moreover, rearing habitat would generally be protected by flows that are suitable for spawning. Hence, the remainder of this section evaluates upstream passage and spawning habitat needs at the regional scale. The evaluation will demonstrate that specifying a MBF to protect spawning habitat will generally protect upstream passage needs as well.

E.1 MINIMUM BYPASS FLOWS THAT PROTECT UPSTREAM PASSAGE

Upstream passage flow needs for adult anadromous salmonids depend in part on the channel size, which reflects drainage area and runoff. Generally, in the larger streams of the Sonoma Creek and Russian River basins, late fall and early winter base flows appear sufficient to enable upstream migration of adult Chinook salmon (Entrix 2004; SEC et al. 2004). In small streams, most upstream passage may occur during freshets (MTTU 2000). A regional analysis of upstream passage flows for adult salmon and steelhead in the Salmon and Clearwater River basins in Idaho indicated that for small basins (mean annual flows less than about 25 cfs), upstream passage was afforded in riffles at flows averaging about twice the mean annual flow (R2 2004). In larger basins, the average minimum passage flow was about half the mean annual flow or less depending on stream order, but spawning flows were always higher. As a result, passage was never a limiting factor.

Data from Idaho (R2 2004), Deitch (2006) and the validation sites were compiled and evaluated to compare upstream passage flow needs against drainage area and mean annual flow (see Appendices G and H for derivation and results). These two metrics are easy to estimate (and thus practical for Policy implementation), and reflect location in the drainage network and channel size. Upstream passage flow needs were defined as the minimum flow needed to provide passage over riffle crests and other locations in the channel where depth was most constricted. Passage depths were evaluated for the 2006 validation sites and compared with previously collected data, including data from Idaho (R2 2004) and from various studies in the Policy area (Entrix 2004; Deitch 2006). Mean annual flow was approximated for the various sites using nearby stream gages.

Plots of passage flow needs (scaled by mean annual flow) against drainage area indicated the existence of general relations for specific passage depth criteria that may be used to determine protective upstream passage flow requirements at any drainage network location in the Policy area (Figure E-1). Multiple linear regression analysis was consequently performed to derive a general relationship between passage flow need, mean annual flow, drainage area, and passage depth criterion. Data from Idaho (R2 2004), Deitch (2006) and the validation sites were first transformed into log-10 space, and then regressed. The validation site data consisted of minimum passage flows derived from passage habitat-flow curves (shown in Appendix H) and calculated for the various minimum passage depth criteria listed in Table G-4 of Appendix G. The data sets were used in a least squares, log-linear multiple regression analysis to develop an equation for passage flow based on drainage area. The equation was developed by first taking the estimated passage flow needs, $Q_{fp,}$ for each site and dividing it by the estimated mean annual flow, $Q_{m,}$ for each site. The log of the ratio of Q_{fp} / Q_m and the log of DA for each site was used in a regression analysis of all data points to develop a relationship for estimating minimum passage depths (MPD). Figure E-2 shows the resulting relationship that is described by the following equation:

$$Q_{fp} = 19.3\, Q_m\, D_{min}^{2.1}\, DA^{-0.72} \qquad \text{(E.1)}$$

Where Q_{fp} = the minimum fish passage flow (cfs), Q_m = mean annual flow (cfs), D_{min} = minimum passage depth criterion (feet), and DA = drainage area (mi^2). The relation appears to be descriptive of streams over a region broader than the Policy area, and is generally consistent across passage depth requirements. That is, a stream location with a given drainage area and mean annual flow is predicted to require on average, more flow for a larger magnitude passage depth criterion than for a shallower criterion in order to provide the respective passage depths over riffles.

The 19.3 coefficient corresponds to the least squares intercept estimate plus three standard errors. This adjustment results in approximating an envelope curve for each passage depth criterion (i.e., an upper 99% confidence limit; Neter et al. 1983). The minimum passage depth and drainage area exponents in Equation (E.1) are the least squares coefficient estimates. The predicted regional MPD curves for specific passage depth criteria do not envelope all of their relevant data, this is shown in Figure E-2 at sites with data points that plot above a given MPD criterion line. As each data point depicted in Figure E-2 has site-specific error influencing its plotting position in the graph (see Section D-5 in Appendix D). Equation (E.1) may still be protective of upstream passage at these sites, unless passage is highly restricted at one location due to atypical site-specific conditions.

Two studies were identified that permitted evaluation of Equation (E.1)'s predictive reliability. In the first, Snider (1985) estimated that passage by steelhead over a critical riffle in lower Brush Creek near Manchester, California, occurred at flows greater than 15 cfs. As a comparison, Equation (E.1) predicts a minimum passage flow of 55 cfs, based on a minimum feasible

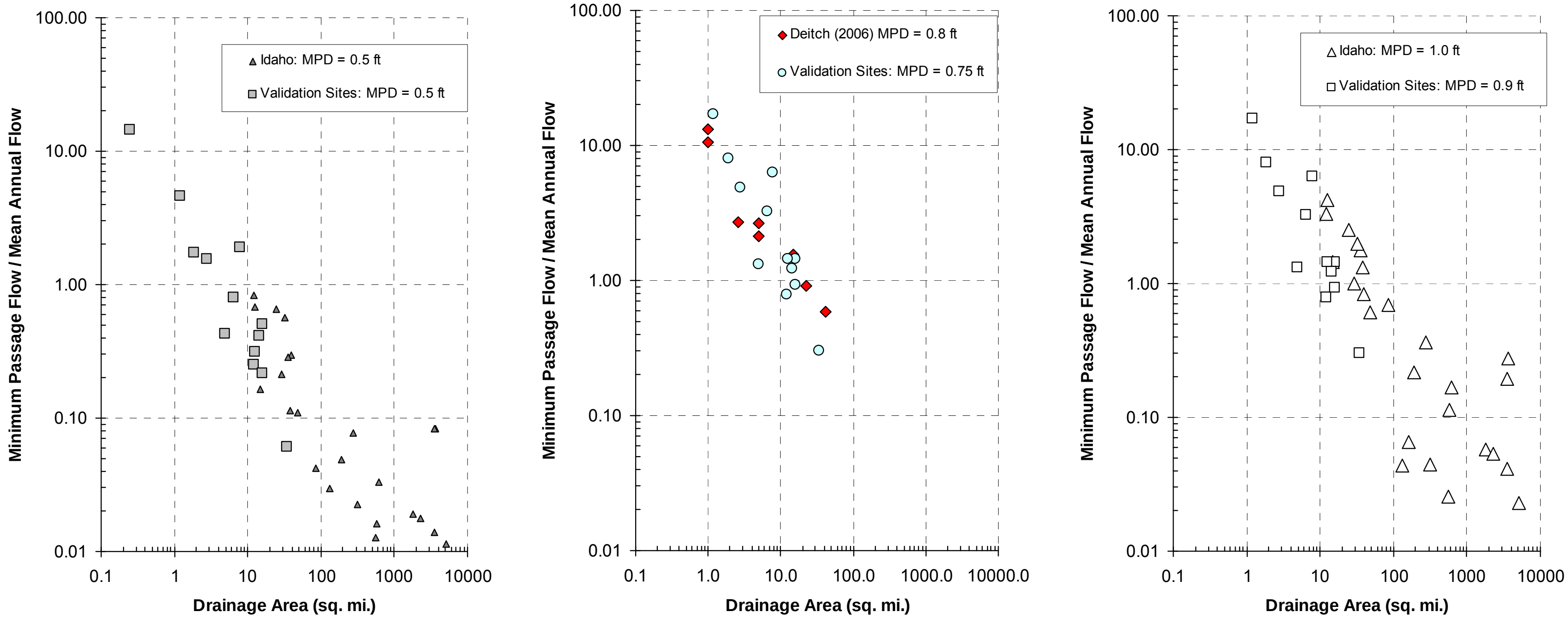

Figure E-1. Variation of estimated minimum upstream passage flow needs, scaled by mean annual flow, with drainage area for selected minimum passage depths (MPD) in riffles.

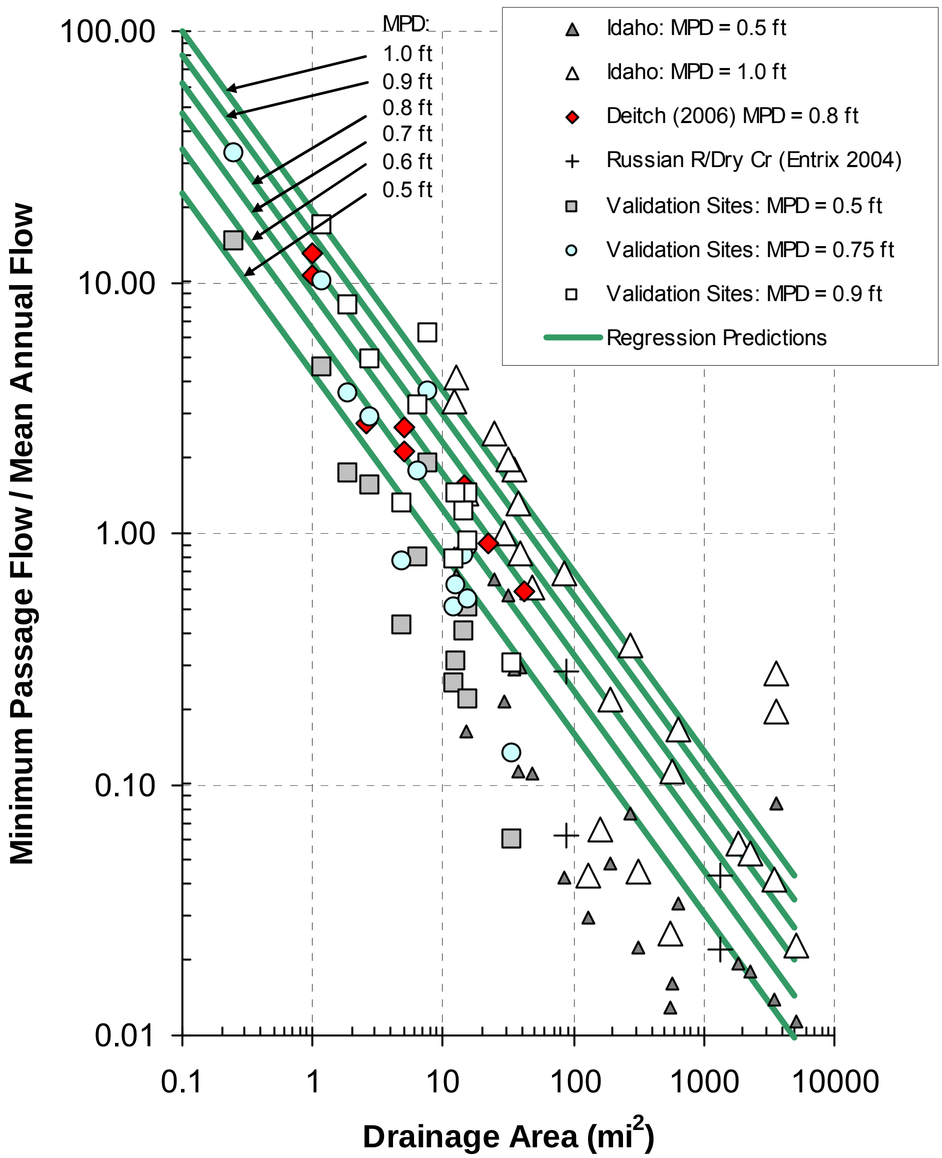

Figure E-2. Comparison of regression predictions for minimum upstream passage flow based on the data presented in Figure E-1, scaled by mean annual flow and plotted against drainage area. The prediction lines for selected minimum passage depth (MPD) criteria are indicated by arrows.

passage depth criterion of 0.7 ft (see Appendix G), 16 mi^2 drainage area, and 44 cfs mean annual flow (SWRCB 1997). This predicted value is about 3.6 times higher than the 15 cfs estimated based on a site-specific evaluation which suggests that application of Equation (E.1) would likely be conservatively protective in lower Brush Creek.

In the second study, Bratovich and Kelley (1988) determined through observation and analysis that a minimum flow of 35 cfs in Lagunitas Creek at Irving Bridge (near Samuel P. Taylor State Park, California) was needed for coho salmon passage over five critical riffles. The nearby Lagunitas Creek 2006 validation site drainage area is 34.3 mi^2 and estimated unimpaired mean annual flow is approximately 72 cfs. The passage flow predicted by Equation (E.1) for this stream at a depth of 0.6 ft is 37 cfs. This estimate is similar to the value determined by Bratovich and Kelley (1988), suggesting that the equation would also provide a reasonable prediction of minimum passage flow at this site.

Based on the above comparisons and the wide range of stream sizes and drainage areas used to derive Equation (E.1), it can be concluded that Equation (E.1) will give predictions of minimum passage flow that are reasonably protective of upstream passage flow needs at the regional scale. However, Equation (E.1) may not fully protect sites that have higher requirements due to unusual site specific conditions.

E.2 AVAILABLE DATA DESCRIBING MINIMUM INSTREAM FLOWS THAT PROTECT SPAWNING HABITAT

As in the case for upstream passage, the amount of flow needed to support spawning habitat generally increases relative to mean annual flow with decreasing basin size (Rantz 1964; Collings et al. 1972b; Smith and Sale 1993; MTTU 2000; Hatfield and Bruce 2000; Vadas 2000). For streams within the Policy area, this relationship may be stronger for steelhead than for Chinook or coho salmon (Vadas 2000). For smaller streams in the Policy area, preferred flows for both salmon and steelhead spawning may occur during a relatively short period of time, during and immediately following storms (e.g., Snider 1984; MTTU 2000).

In the following, spawning flow requirements are evaluated according to drainage area and mean annual flow. These metrics are relatively simple to determine and reflect the influence of important basin size and runoff effects on spawning habitat availability and channel size. Use of mean annual flow as a scaling metric reflects total basin runoff characteristics irrespective of hydrologic process (e.g., snowmelt vs. rainfall runoff).

This section identifies the results of previously published regional and local studies of spawning habitat flow requirements, and compares them with data collected from the validation sites as part of this project. Appendix G describes the methods used to analyze validation site data; Appendix H presents resulting habitat-flow curves.

E.2.1 Published Regional Studies of Spawning Flow Requirements

A number of regional instream flow studies have results applicable to assessing the protectiveness of the MBF for spawning flows. These are summarized below and compared with the analyses of data collected in the validation sites listed in Table G-1 of Appendix G.

In the first study, Rantz (1964) collected data describing Chinook salmon spawning habitat conditions as a function of flow in the Eel and Mad River basins in northern California. Optimum spawning flow was defined as the lowest flow rate maximizing spawnable area with suitable depths, velocities, and substrates. Rantz (1964) used threshold values of depth and velocity to define suitable spawning habitat; an area was either suitable or it was not. Suitable widths were measured across transects at various flows, and converted to total area. Rantz (1964) calculated a ratio of spawnable area with suitable depths and velocities to total area of spawning gravel. While this ratio indicated the same optimum flow as the suitable spawnable area, it also provided an index of the relative availability of spawnable substrates at various flows, with a maximum value of 100% representing all suitable gravels being available at a given flow. Rantz (1964) developed a regression equation for optimum flow for Chinook salmon, using data from nine streams:

$$Q_{Optimum} = 0.89(Q_m)^{1.09}\left(\frac{R_w}{DA}\right)^{1.44} \qquad \text{(E.2)}$$

Where Q_m = mean annual flow (cfs; range = 37-1,280), R_w = stream width (ft; range = 31-271), and DA = drainage area (mi^2; range = 16-393). Although Rantz (1964) noted that the small number of sites used likely limited predictive reliability, some trends were apparent. He noted that for streams with equal mean annual flow, the preferred spawning flow increased with channel width because higher flows were required to achieve the same depths and velocities. Streams that were disproportionately wide relative to drainage area had higher preferred flow than narrower streams.

Several analogous studies were conducted subsequently by the USGS in both rainfall- and snowmelt-runoff systems in Washington State. A pilot study was conducted by Collings et al. (1972a,b) in western Washington. Using data from eight streams, Collings et al. (1972a,b) developed an alternative relationship to that of Rantz (1964) that indicated the magnitude of the optimum spawning flow varied with measures of channel size, and included terms for drainage area, channel slope, bankfull width, and bankfull depth. The influence of channel slope variation was minor, as indicated by a regression exponent near 1.0. Additional analyses were completed by (Collings 1974), and two USGS publications, one for steelhead (Swift 1976) and the other for Pacific salmon (Swift 1979). Swift (1976) derived the following equation for predicting optimum spawning flows for steelhead in streams with drainage areas ranging between 3.5-327 mi^2:

$$Q_{Optimum(Steelhead)} = 16.8(DA)^{0.666} \tag{E.3}$$

Swift (1979) presented the following analogous equations for coho and Chinook salmon based on drainage area and mean annual flow, respectively:

$$\begin{aligned} Q_{Optimum(Coho)} &= 6.78(DA)^{0.756} \\ Q_{Optimum(Coho)} &= 2.13(Q_m)^{0.771} \end{aligned} \tag{E.4a, b}$$

$$\begin{aligned} Q_{Optimum(Chinook)} &= 15.9(DA)^{0.698} \\ Q_{Optimum(Chinook)} &= 4.22(Q_m)^{0.747} \end{aligned} \tag{E.5a, b}$$

Equations were also presented by Swift (1976, 1979) for rearing juvenile salmonids, based on wetted area in the main channel for food production during summer low flow. Those equations resulted in flow recommendations that were inherently lower than flows required for spawning.

The spawning flow data of Rantz (1964) and Swift (1976, 1979) are compared in Figure E-3. Equations E.4 and E.5 are also depicted, along with the results of our regression analysis of the Swift data for steelhead. The effects of channel size and location in the drainage network are evident in the decreasing trend in the data. The California and Washington Chinook data scatter overlap, and indicate greater instream flow needs for spawning than coho salmon for a given drainage area. The steelhead data scatter overlaps with Chinook and coho data.

A considerable data set was also collected between 1989-1995 in Idaho as part of the Snake River Basin Adjudication. The study used the PHABSIM system to define habitat-flow needs for spawning and other life stages for steelhead, Chinook salmon, and other species (Bovee and Milhous 1978; Bovee 1982; R2 2004). PHABSIM calculates habitat area based on the relative suitability of depths, velocities, and substrates over a range of flows, resulting in a habitat area-flow curve. The metric of habitat area is called Weighted Usable Area (WUA). For the present analysis, flow recommendations for steelhead spawning, as defined by the peak of the WUA vs. flow curve, were compiled with mean annual flow estimates. It should be noted that the peak WUA-based flow recommendations differ from the peak optimum habitat curves of Rantz (1964) and Swift (1976, 1979). The Idaho data for steelhead represent maximum spawning habitat as

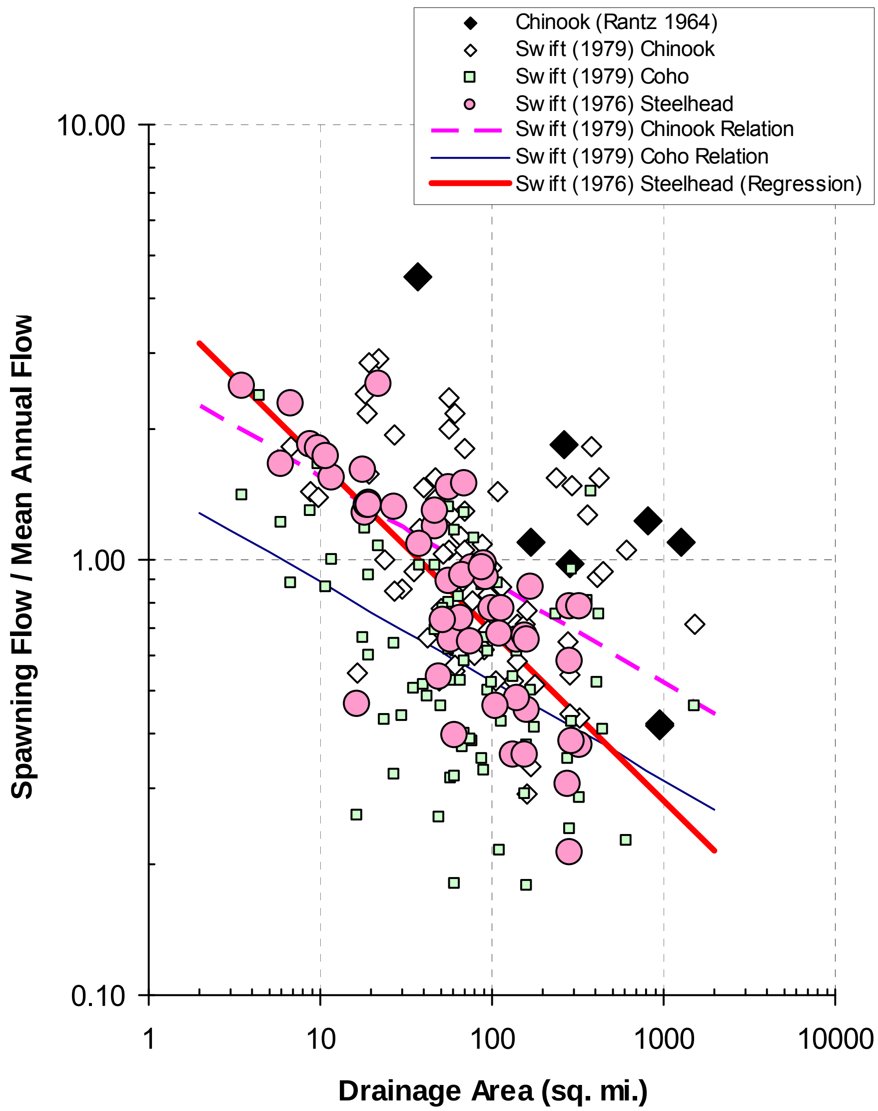

Figure E-3. Comparison of minimum instream flow recommendations for spawning steelhead, Chinook, and coho in streams surveyed variously by Rantz (1964) and Swift (1976, 1979) in California and Washington, distinguished by drainage area. The spawning flow is scaled by the mean annual flow to account for channel size effects on spawning flow needs.

defined by a gently peaked curve generated by PHABSIM, in which areas with sub-optimal depths and velocities contribute to the total amount of habitat predicted. The discrete results of Rantz (1964) and Swift (1976, 1979) are based on only summing areas with optimal depths and velocities. A re-evaluation of their results using PHABSIM, would likely result in a prediction of habitat amounts closer to the minimum flow threshold (also called inflection) point in Figure D-1. In addition, the suitability curves used to define steelhead and Chinook depth and velocity preferences in Idaho were equivalent, reflecting similar regional habitat requirements. As a consequence, the data of Swift (1976, 1979) for steelhead and coho plot generally lower than the Idaho data, while the data of Rantz (1964) and Swift (1979) for Chinook plot closer to the Idaho data for steelhead spawning (Figure E-4). The analysis of the Idaho data corroborates a channel size effect when defining instream flow needs for spawning, as reflected by drainage basin area and mean annual flow. The collective data scatter for all data sets indicates there are upper and lower thresholds that may be defined by relatively simple, practical formulae for prescribing the Upper MBF (MBF3) and Lower MBF (MBF4) alternatives for the MBF element of the Policy.

Recently, Hatfield and Bruce (2000) compiled the results of instream flow studies conducted throughout the United States that were based on the use of PHABSIM. The analysis included the Idaho data. Hatfield and Bruce (2000) found an essentially log-linear relation between the flow maximizing WUA and mean annual flow (range = 4.1-15,100 cfs) for adult and spawning steelhead trout and Chinook salmon, and for other life stages and species. The regression derived for WUA-maximizing flow ($Q_{optimum}$; in cfs) for spawning steelhead was:

$$Q_{optimum\ (steelhead)} = 4.37 \times 10^{-15}\ Q_m^{\ 0.618}\ \text{Longitude}^{7.26} \qquad \text{(E.6)}$$

The regression derived for spawning Chinook was:

$$Q_{optimum\ (Chinook)} = 3.49 \times 10^{-23}\ Q_m^{\ 0.682}\ \text{Longitude}^{11.042} \qquad \text{(E.7)}$$

Regression prediction intervals were relatively large in magnitude, indicating considerable uncertainty in the predictions of basins that were not included in the original data set used to develop the relations. This finding is consistent with the observed scatter in Figures E-3 and E-4 in which it is possible for streams that are similar in terms of hydrologic characteristics to have different instream flow needs for spawning based on undescribed sources of variability such as local slope, lithology, and other factors. Nonetheless, they consistently found that the WUA- maximizing flow decreased relative to mean annual flow with increasing basin or channel size. They inferred that the decline in proportion of mean annual flow with increasing stream size explained in part why PHABSIM- and simple hydrologic-based flow recommendations are not consistent or proportional for all streams.

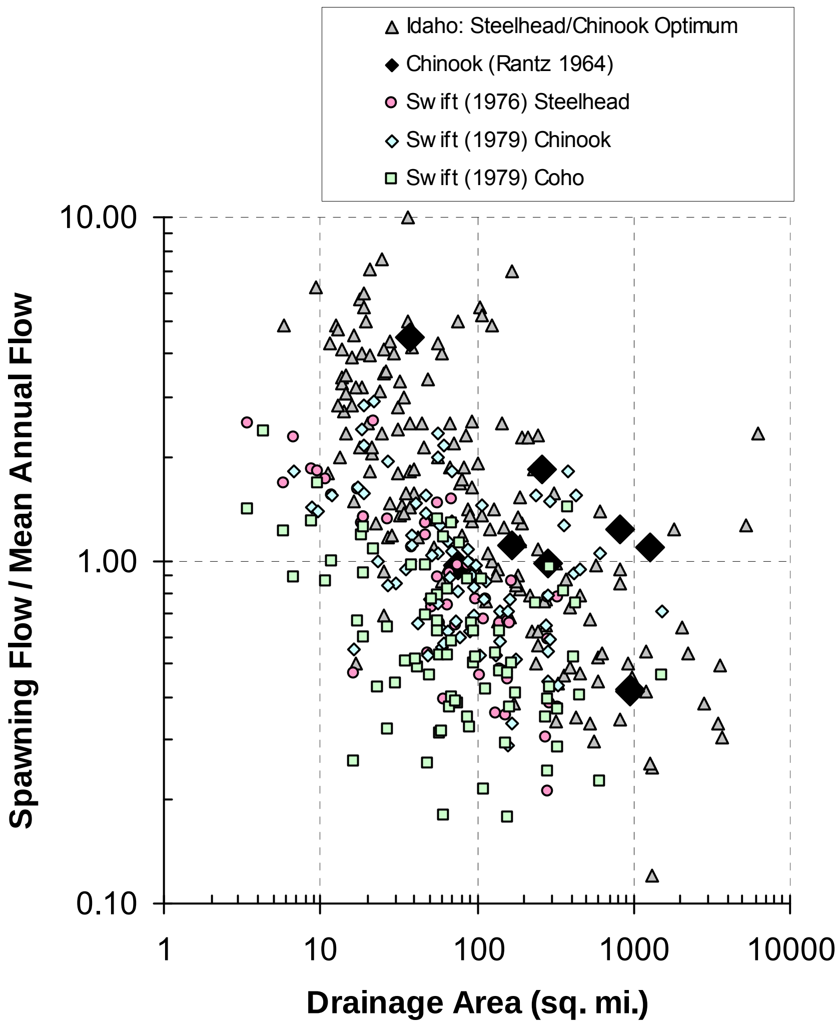

Figure E-4. Comparison of minimum instream flow recommendations for streams surveyed variously by Rantz (1964) and Swift (1976, 1978) in California and Washington, with optimum steelhead spawning flows determined for Idaho streams (R2 2004), distinguished by drainage area. The spawning flow is scaled by the mean annual flow.

Hatfield and Bruce (2000) proposed that the regressions they developed could be used in the context of project scoping, research planning, and adaptive management. In the latter case, they proposed that their relations could be used to estimate a value and range of flows for more detailed experimentation and monitoring. In that sense, the regional relations they developed provide an independent means for assessing the protectiveness of various MBF thresholds.

E.2.2 Previous Instream Flow Recommendations in the Policy Area Related to Anadromous Salmonid Spawning

There have been few intensive instream flow studies conducted in Policy area streams, and the work that has been performed has occurred in relatively large channels. The State Water Board summarized optimum spawning flow estimates derived from habitat-flow data collected in Big Sulphur Creek, Dry Creek, Brush Creek, and Lagunitas Creek (SWRCB 1997). This information is reproduced in Table A-1 in Appendix A of this report.

Three reports were identified in which informal minimum instream flow recommendations were made for selected streams in the Policy area (Walker Creek - Kelley 1976; Pine Gulch Creek and Redwood Creek - Anderson 1978; Redwood Creek - Snider 1984). In another series of reports, Entrix (2002, 2004) reported general minimum instream flow needs for the Russian River and its major tributary, Dry Creek, based on anecdotal data and observations. Suitable spawning conditions for steelhead and Chinook were thought to occur at flows above about 100 cfs and 130 cfs, respectively in the Russian River, and above about 30 cfs and 40 cfs respectively in Dry Creek (Entrix 2004). These collective recommendations appear to represent minimum acceptable instream flows below which spawning habitat would not be protected. These estimates were evaluated here using data from nearby gages for an order of magnitude estimate of spawning flow needs.

In addition, the DWR (1982) published an inventory of instream flow requirements for streams throughout the state, including several distributed across the Policy area. For the purposes of deriving an MBF alternative, the flows listed in DWR (1982) for the winter period were assumed to be intended to protect steelhead and salmon spawning. The magnitudes of the flow requirements were generally lower than the other flow recommendations reviewed for a given stream size. Consequently, it was presumed that the numbers represented characteristic negotiated instream flow levels that serve to balance instream flow needs of fish with other water uses.

The various flow recommendations identified above are compared in Figure E-5, scaled by mean annual flow and plotted against drainage area. The data in Figure E-5 generally plot within the same scatter as the data depicted for steelhead and coho in Figure E-4, albeit within the lower range of the overall data scatter. Most of the data in Figure E-5 indicate a general trend of decreasing proportions of mean annual flow needed for spawning, with increasing channel size. It is interesting that the studies reviewed by the State Water Board (SWRCB 1997) do not, but the reason is unclear.

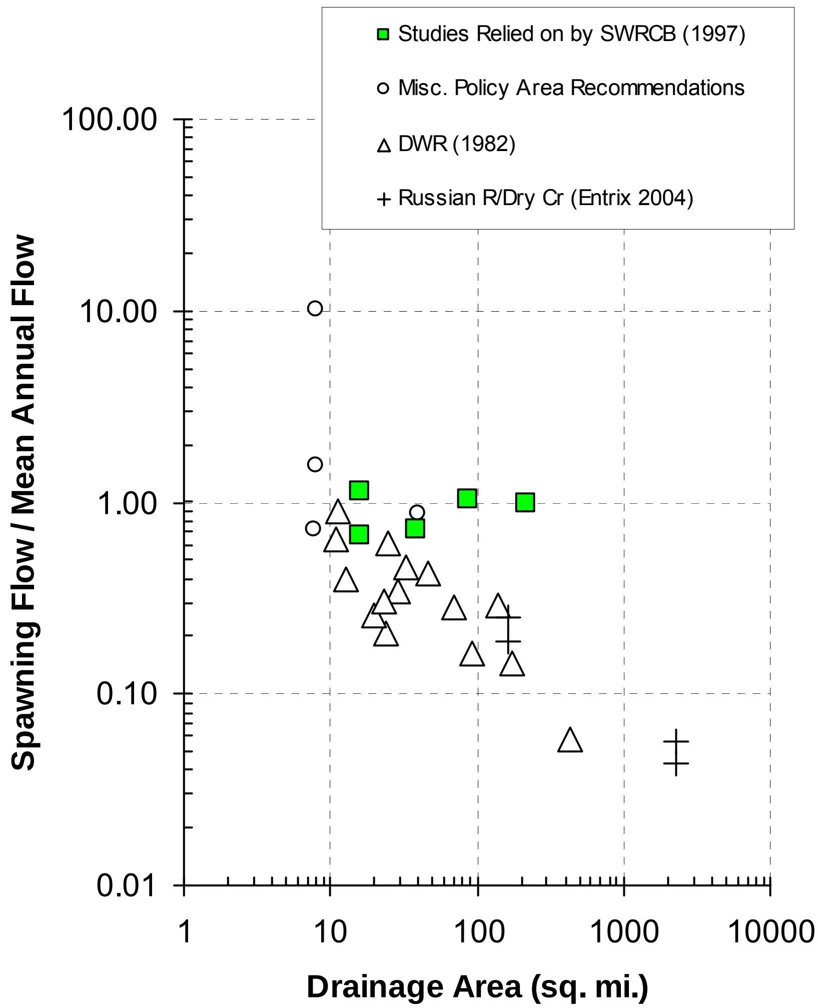

Figure E-5. Comparison of minimum instream flow recommendations for anadromous salmonid spawning in streams in the Policy area, distinguished by drainage area. The spawning flow is scaled by the approximate unimpaired mean annual flow.

Vadas (2000) reviewed various studies of instream flow needs of steelhead and coho in streams located north and south of the Bay Area, including those reviewed by the State Water Board (SWRCB 1997) and DFG-NMFS (2002). Comparable studies from northern California and Washington State were also reviewed. In general, upstream passage flow needs appeared to be similar for steelhead and coho, but steelhead had higher instream flow needs for spawning. Vadas (2000) proposed that the differences reflected general body size, with the smaller coho spawning in shallower, slower habitats. Vadas (2000) also determined that upstream migration and spawning required more water than rearing life stages in California and elsewhere. Optimal instream flow needs were determined to be around 14% to 49% of the mean annual flow for rearing and fry life stages, and 80% to 114% of the mean annual flow for spawning.

E.2.3 Comparison of Validation Site Spawning Flow Requirements With Previous Studies

As described in Appendix G, hydraulic and habitat data were collected in 2006 from 13 validation sites in the Policy area representing drainage areas from around 15 mi^2 and smaller. These data were analyzed for habitat suitability as a function of flow; see Appendix H for respective habitat-flow curves. The validation site results for the smallest flow maximizing spawning habitat (see Appendix H for more complete description) were compared with spawning flow predictions based on Swift (1976) and Hatfield and Bruce (2000). Results for steelhead are presented in Figure E-6 (the scatter for coho and Chinook plot within the same range and trend as depicted for steelhead).

In general, there is a decreasing trend with increasing drainage basin area seen in Figure E-6. The validation site results generally encompass the other regional-based predictions, and are similar in magnitude. These observations indicated that the validation site habitat-flow analyses could be used to help define the Upper MBF (MBF3) and Lower MBF (MBF4) alternatives, based on spawning habitat requirements.

E.3 DEVELOPMENT OF MINIMUM BYPASS FLOW POLICY ELEMENT ALTERNATIVES PROTECTING SPAWNING HABITAT

The consistent trends seen in the various data sources reviewed above indicate that it should be possible to define Upper MBF (MBF3) and Lower MBF (MBF4) alternatives for protecting spawning habitat while accounting for channel size effects. Envelope curves were determined for each alternative level of protectiveness by first developing least-squares regressions through data points considered most representative of the respective alternative's basis, and then shifting each regression equation prediction upwards by 3 standard errors about the regression constant. This procedure results in an approximate 99% prediction limit (Neter et al. 1983). Data points used to represent each alternative, Upper MBF (MBF3) and Lower MBF (MBF4) are listed in Table E-1. Data from SWRCB (1997) were not used because (i) they were derived in a different manner from the Swift and validation site data and (ii) did not follow the

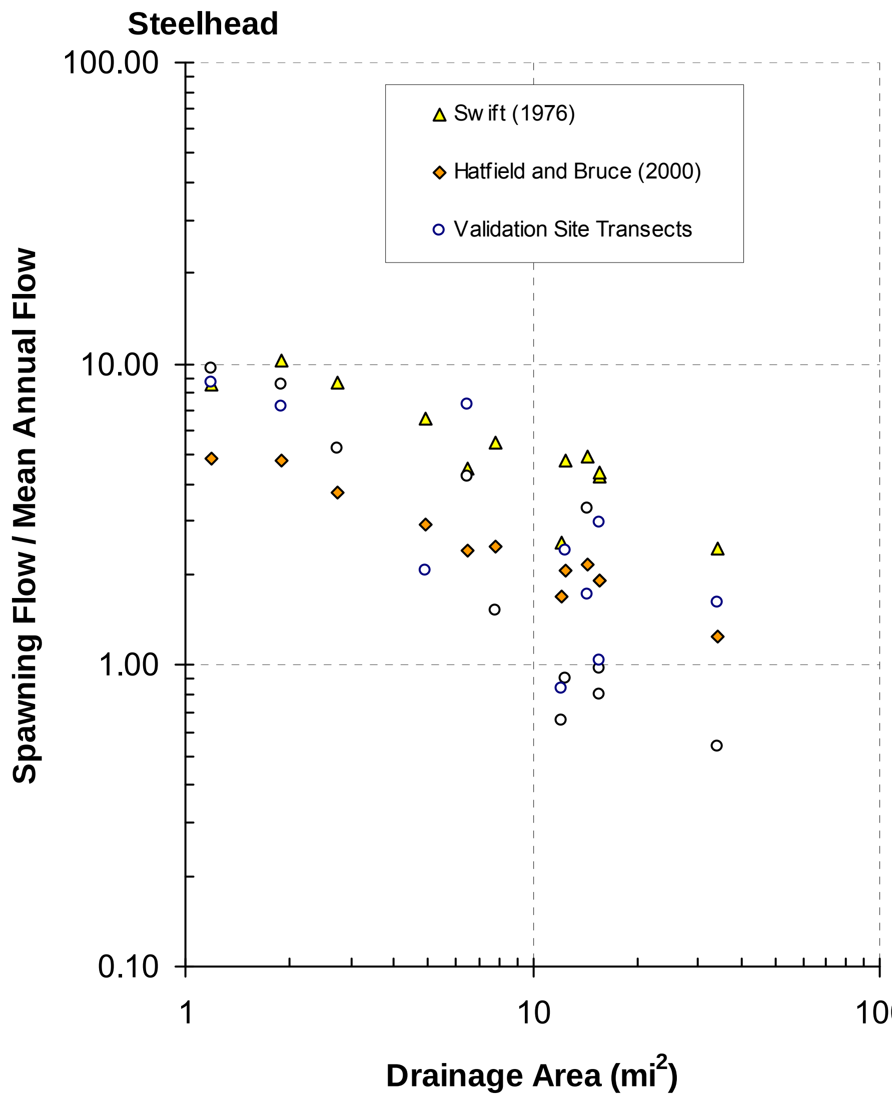

Figure E-6. Comparison of minimum instream flow recommendations for steelhead spawning in Policy area streams sampled in 2006 with predictions based on other regional studies, distinguished by drainage area. The spawning flow is scaled by the approximate unimpaired mean annual flow.

same decreasing trend with stream size seen in the other data used to generate the MBF4 line. The Idaho data were not used because the steelhead habitat suitability index curve for depth that was used there to calculate spawning habitat-flow curves was set identical to the curve for Chinook salmon, whereas in the Policy area, steelhead appear to use slightly shallower depths (see Table G-7 in Appendix G).

Table E-1. Source Data Used to Develop MBF Alternatives

Source	Description	MBF Alternative
Swift (1976)	Flow which provided the maximum spawning habitat availability, above which no further increase of habitat is provided	Upper MBF
Validation Sites 2006	Flow which provided the maximum spawning habitat availability, above which no further increase of habitat is provided	Upper MBF
DWR (1982)	Negotiated minimum instream flow requirements in the Policy area	Lower MBF
Kelley (1976), Anderson (1978) and Snider (1984)	Minimum spawning flow recommendations	Lower MBF
Entrix (2004)	The lowest anecdotal spawning flow for steelhead in Dry Creek below Warm Springs Dam	
Validation Sites 2006	Flow which provided the marginally useable spawning habitat conditions, below which no habitat is available	Lower MBF

E.3.1 Basing the MBF Criterion on Steelhead Habitat Needs

At the site-specific level, protectiveness reflects the species that are or might be present, which potentially introduces a layer of complexity to the development of Policy elements depending on the site in question. The three anadromous species of concern in the Policy area have slightly different spawning habitat requirements, and may also differ in their spatial distribution. Chinook, for example, tend to spawn lower in the drainage network than coho in systems where both occur. In contrast, steelhead that use the same streams as coho and Chinook, generally migrate farther upstream than coho (Shapovalov and Taft 1954). Nevertheless, the instream flow needs of steelhead tend to overlap the other two species' (Figures E-3, E-4). Indeed, based on the similarity of habitat suitability criteria between steelhead and Chinook, providing suitable spawning flows for steelhead should also provide spawning habitat for Chinook. Likewise, the provision of suitable flows for steelhead should also be protective of coho spawning, since coho suitability criteria would result in lower flows.

As a result, steelhead were selected and used as the "indicator species" for development of MBF alternatives and for later evaluation of the protectiveness of flow-related elements relative to spawning habitat for all three target anadromous salmonid species.

E.3.2 Development of the Upper MBF Alternative

The Upper MBF alternative was developed based on the spawning flow data of Swift (1976) and the spawning flows derived for the 2006 validation sites. Both sets of data represented the lowest flow at which maximum spawning habitat availability occurred for steelhead (Figure E-7), but were based on slightly different depth suitability criteria. The validation site data were based on a minimum suitable depth criterion of 0.8 ft (Table G-7 in Appendix G), whereas the data of Swift (1976) were based on a depth criterion equal to 0.7 ft. An initial sensitivity analysis of the validation site data indicated that there were negligible differences across sites for the optimum flows represented, whether a minimum depth criterion of 0.8 ft or 0.6 ft was used. As a result, the Swift (1976) data were combined with the validation data results based on the minimum depth criterion of 0.8 ft selected for the Policy area (see Appendix G) to develop a regional relation, with the Swift (1976) data representing more of the larger drainage area streams, and the validation data representing smaller drainage area streams.

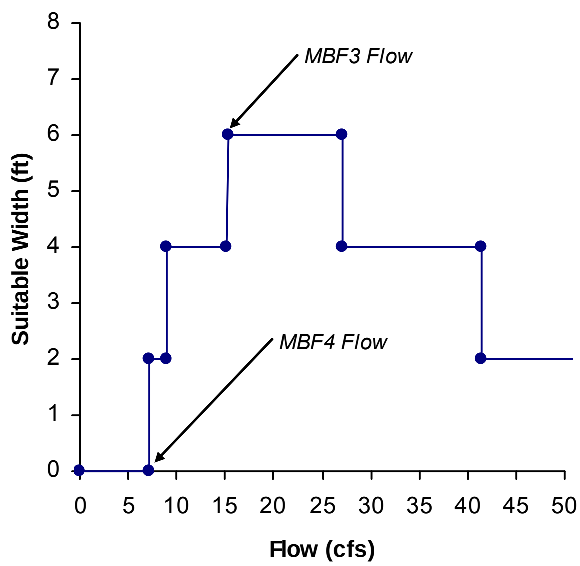

Figure E-7. Depiction of flows used in the development of the Upper MBF (MBF3) and Lower MBF (MBF4) alternatives, as derived from validation site spawning habitat-flow curves shown in Appendix H.

The data sets were used in a least squares, log-linear least squares regression analysis to develop an equation for MBF (Q_{MBF}; cfs) based on drainage area (DA; mi^2). The equation was developed by first taking the estimated Q_{MBF} for each site and dividing it by the estimated mean annual flow (Q_m) for each site. Drainage area was reported by Swift (1976) and by the USGS for the respective validation site gages. The Q_{MBF} was then divided by Q_m and the log of Q_{MBF} /

Q_m and the log of DA for each site used in a regression analysis of all data points to develop the following linear equation:

$$\text{Log}\,(Q_{MBF} / Q_m) = -0.4837(\text{Log DA}) + 0.7870 \qquad \text{(E.8a)}$$

Since this mean regression line would only protect roughly half of the stream sites in the data set, the log-regression intercept estimate (0.7870) was adjusted upwards by 3 standard errors of regression (3 x 0.0619) above the coefficient estimate to generate an approximate 99% prediction interval for the intercept (Neter et al. 1983). This procedure produced a log-linear equation that shifted the regression line upward among or above most of the data points. The equation should therefore be conservatively protective of the majority of the stream sites used in the analysis. Solving the shifted linear equation for Q_{MBF} and rounding coefficients to 2 significant figures yields the following equation:

$$Q_{MBF} = 9.4\, Q_m\, (DA)^{-0.48} \qquad \text{(E.8b)}$$

This equation represents a suggested MBF for the Upper MBF (MBF3) alternative for protecting spawning habitat and is plotted in Figure E-8 with the respective data used. The MBF3 line would protect most of the streams analyzed using the depth and velocity criteria developed in Appendix G. Data points above the line are not substantially higher, and the “within-site” errors would likely extend the confidence intervals about the points to below the regression line of Equation (E.8) (cf. Williams 1996). In addition, the validation site transects were generally placed over locations with high quality spawning gravels that had shallower depths, compared to other spawning locations in pool tail regions. Thus, the recommended flow threshold indicated by Equation (E.8) can be considered as conservatively protective of the deeper spawning locations in these streams.

E.3.2.1 Lower and Upper Drainage Area Limits When Applying the Upper MBF Regression Equation

It is important to note that the confidence in regression-based predictions decreases when the relation is used to predict new observations using independent variable data that fall outside the range of the original data set (Neter et al. 1983). Thus, it is important to define the size range of drainage areas for which the Upper MBF (MBF3) equation (Equation E.8) can reasonably be applied.

To estimate the lower limit of drainage area, the stream-by-stream designation of steelhead critical habitat in the Policy was analyzed using the ESRI ArcInfo Geographic Information System (GIS) to determine the drainage areas at the upper extent of critical habitat. A total of 675 drainage basins were identified above the upstream limits to critical habitat. Figure E-9

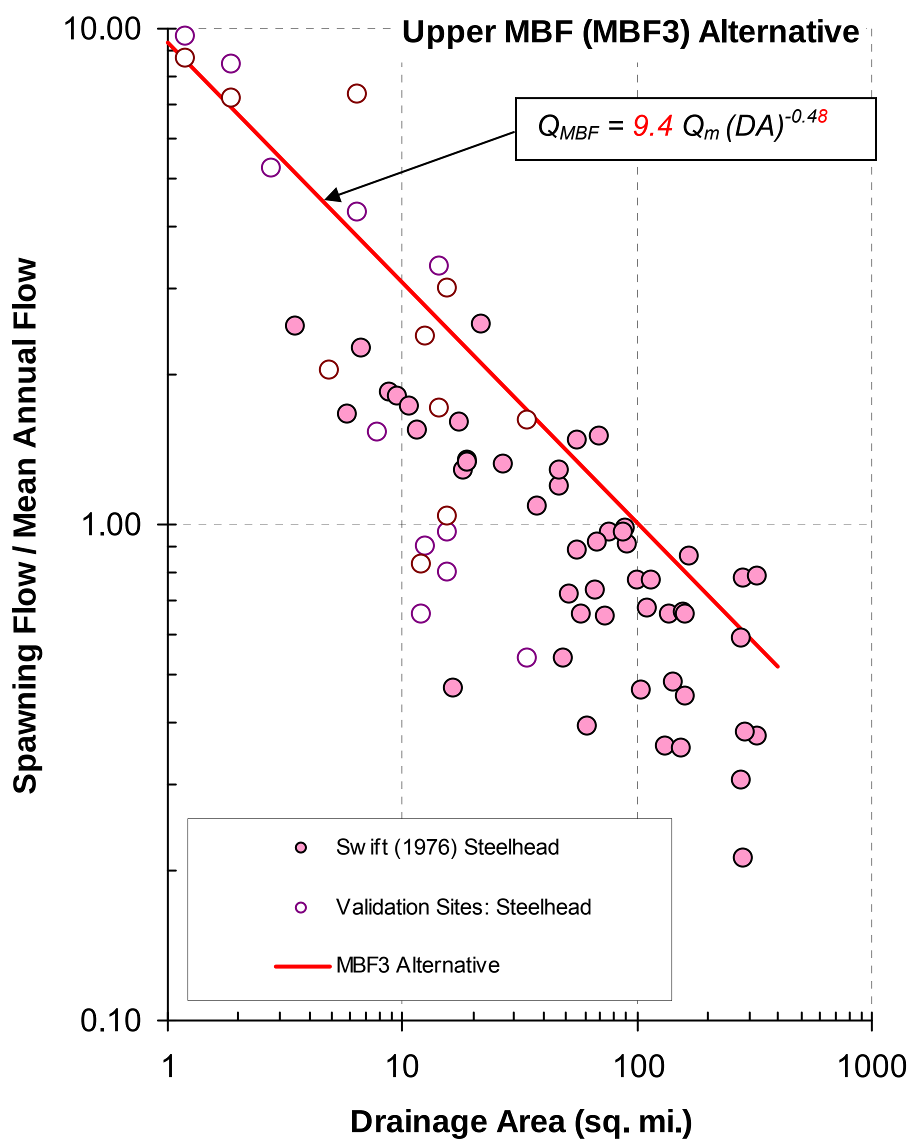

Figure E-8. Upper MBF (MBF3) alternative regression line plotted with the spawning habitat-flow regression data.

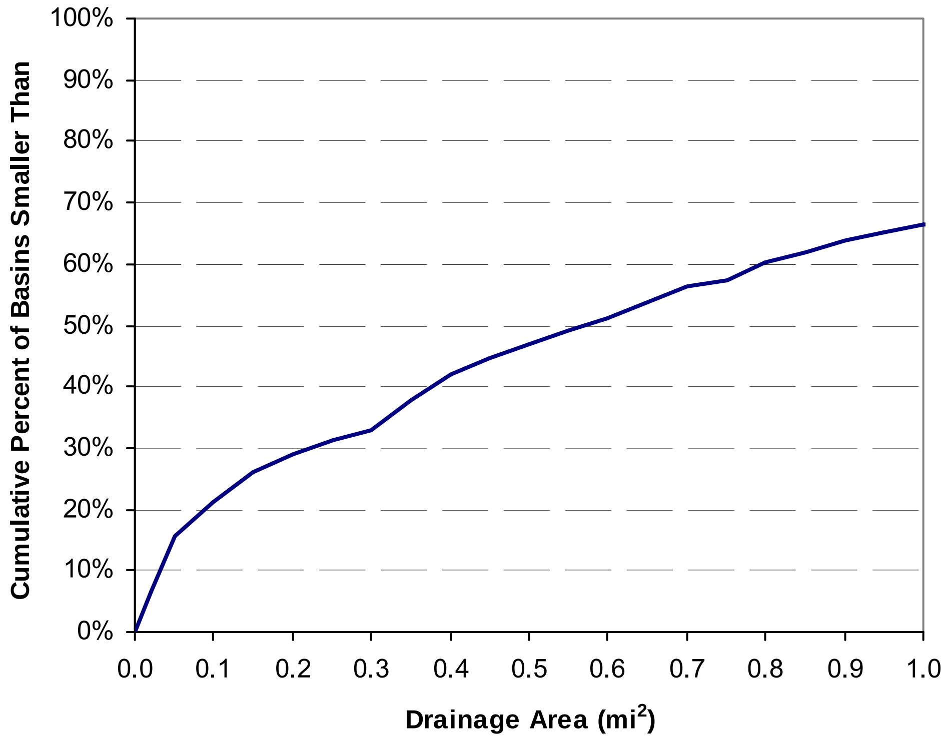

Figure E-9. Percent of headwater basins upstream of steelhead critical habitat in the Policy area with drainage areas smaller than a specified value. For example, roughly half of the delineated headwater basins have a drainage area smaller than 0.6 mi^2.

shows the results of this analysis and indicates that approximately 80% of streams in the Policy area with steelhead critical habitat have drainage areas upstream of the limit of anadromy that are greater than 0.1 mi^2.

Based on the inverse relationship depicted in Figure E-8, which indicates that proportionally more water is needed to meet the protectiveness level as drainage size decreases, there would be no need to apply a regression equation derived for anadromous spawning habitat to non-anadromous habitat in even smaller drainage basins. Doing so would require even more water to be kept instream than is needed to maintain downstream spawning habitats. This suggests that the MBF in non-anadromous habitat should be limited to the flow that meets the MBF requirement for a stream at its upstream point of anadromy. Assuming that the upstream limit of steelhead habitat is known or can be determined for a specific stream, then it should be possible to estimate the required MBF that preserves the regression estimate for that upstream limit. The magnitude of the required flow can be approximated by assuming that the mean annual flow and MBF magnitudes in small basins change proportionally with drainage basin area; i.e., that flow is proportional to $(DA)^b$. Hence, the ratio of MBF in non-anadromous habitat (Q_{MBF-1}) to the MBF at the upstream extent of steelhead habitat in the same channel network (Q_{MBF-2}), would be:

$$\frac{Q_{MBF-1}}{Q_{MBF-2}} = \left(\frac{DA_1}{DA_2}\right)^b \qquad \text{(E.9)}$$

Vogel et al. (1999) estimated an exponent value of 1.1 for the mean annual flow in all of California and parts of western Nevada and southeastern Oregon. However, this estimate was based on a large number of streams that are drier than those found in the Policy area. By comparison, the exponent for Oregon and Washington was around 0.75 (Vogel et al. 1999). It is thus likely that the exponent for mean annual flow in the Policy area is less than or equal to 1.0. The assumption that changes in mean annual flow and MBF in small basins occur in proportion to drainage basin area appears reasonable.

Based on this assumption, it can be shown algebraically using Equations (E.8) and (E.9) that the corresponding MBF limit at any point upstream of steelhead habitat should be approximately equal to $9.4(DA_2)^{-0.48}$ times the local estimated mean annual flow, where DA_2 is the area at the upstream limit of steelhead habitat for the stream in question.

With respect to an upper drainage area limit, extrapolation of Equation (E.8) in large streams would result in recommending low flows relative to mean annual flow. The scatter of the Idaho data in particular, which has better representation of large drainage areas, suggests that the decreasing relation between the MBF/mean annual flow ratio and drainage area is not clearly defined for streams in large drainage areas. In the absence of additional information, it appears reasonable to apply the $0.6Q_m$ level that was originally proposed by the SWRCB (1997) as a lower limit to the MBF in large streams. The $0.6Q_m$ level was based on analyses described by SWRCB (1997), including the observation of other regional criteria of around 60-70% of the mean annual flow, and a review of habitat-flow data suggesting this approximate level for use during dry years. Concern that the $0.6Q_m$ level would not protect small to moderate size drainage basins is not relevant, as smaller basins would be subject to the higher MBF requirements of Equation (E.8). The drainage size marking the transition from the use of Equation (E.8) to application of the $0.6Q_m$ level can be determined by matching the drainage area at which the regression relation predicts the same flow; this occurs at about 295 mi^2.

E.3.3 Development of the Lower MBF Alternative

The Lower MBF (MBF4) alternative was developed to allow for water usage up to a level above which additional diversion would substantially reduce spawning habitat availability. For this, a regression analysis was completed similar to that applied in developing the Upper MBF alternative. The data used in the analysis were extracted from a summary of negotiated instream flow requirements in the Policy area listed in DWR (1982), the recommendations of Kelley (1976) and Anderson (1978), and the lowest anecdotal spawning flow for steelhead in Dry Creek below Warm Springs Dam (Entrix 2004). In addition, the 2006 validation site habitat-flow data summarized in Appendix H were used to estimate minimum spawning flows. These flows, defined as representing marginally useable spawning habitat conditions, were identified as those below which spawning habitat in the pool tail, near the riffle crest, and in runs were no longer available for steelhead and coho (Figure E-7). Validation site results were considered for both species because the majority of the identified negotiated flow recommendations were applied to spawning periods more characteristic of coho and steelhead. The resulting estimates of minimum spawning flow needs for the validation sites plotted along the same scatter trend as the other data (Figure E-10). The overall consistency of the data scatter about a declining trend line suggested that the collective data were suitable for developing the Lower MBF alternative.

The same analytical process used for the Upper MBF was applied in developing the Lower MBF alternative. This resulted in the following least squares, log-linear regression equation which is analogous to Equation (E.8):

$$Q_{MBF} = 5.4\ Q_m\ (DA)^{-0.73} \qquad \text{(E.10)}$$

The 5.4 coefficient corresponds to approximately the upper 99% confidence limit of the least squares estimate of the log-linear regression intercept. This Lower MBF (MBF4) alternative is indicated by the thick envelope line in Figure E-10.

E.3.3.1 Lower and Upper Drainage Area Limits When Applying the Lower MBF Regression Equation

The Lower MBF (MBF4) regression was constrained at the lower range, because it crossed the Upper MBF (MBF3) regression at a drainage area of about 0.10 mi^2. Therefore, for purposes of evaluating protectiveness in streams in smaller drainage areas, the MBF4 alternative was assumed to be the same as for the MBF3 alternative.

The same logic used for specifying a MBF upstream of steelhead habitat as part of the MBF3, applies to the MBF4 (see Section E.3.2). Thus, it can be shown algebraically using Equations (E.10) and (E.9) that the corresponding MBF limit at any point upstream of steelhead habitat should be approximately equal to $5.4(DA_2)^{-0.73}$ times the local estimated mean annual flow at any point upstream of the habitat, where DA_2 is the area at the upstream limit of steelhead habitat for the stream in question.

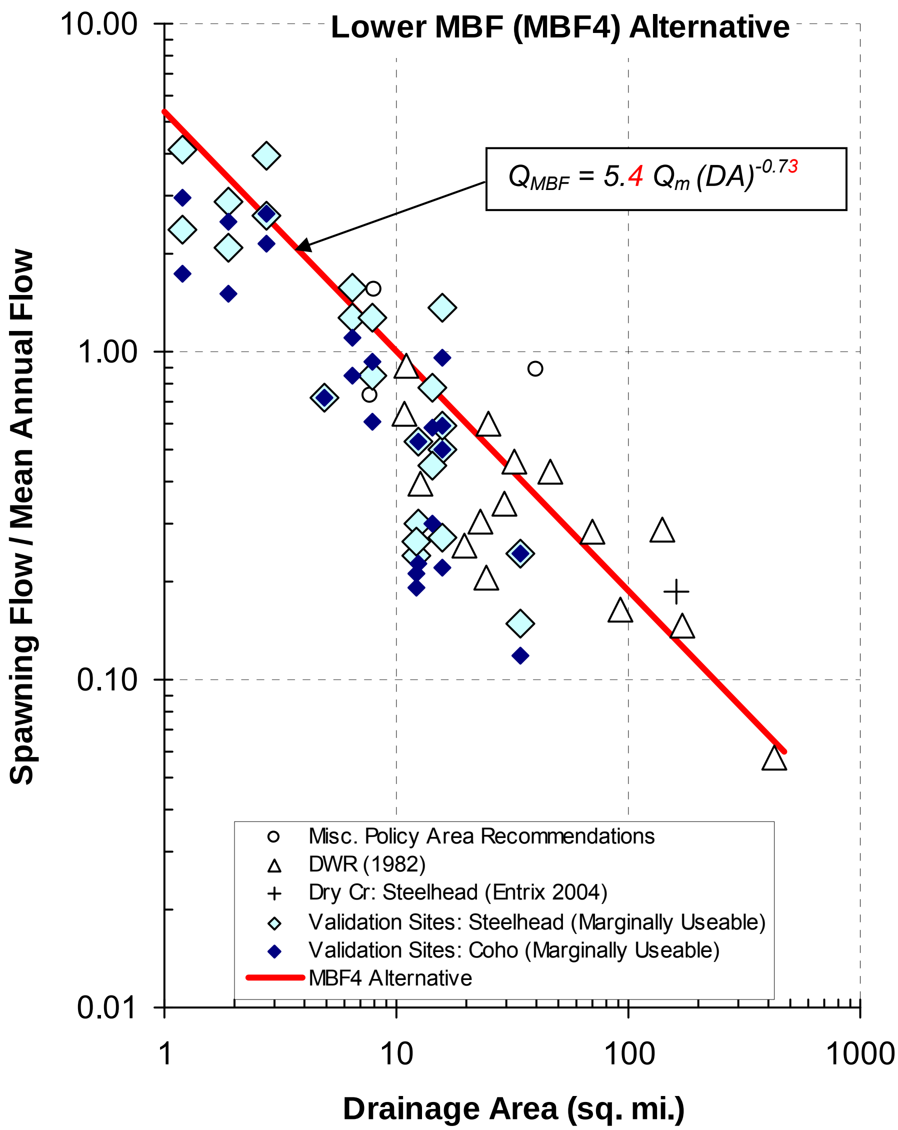

Figure E-10. Lower MBF (MBF4) alternative regression line plotted with the spawning habitat-flow regression data.

With respect to streams in large drainage areas, the lower leg of the MBF4 line was based on the minimum spawning flows reported by Entrix (2004) for the Russian River that were similar in magnitude to the largest drainage area data point from DWR (1982) in Figure E-5. These flows were found to be equivalent to approximately 0.06 times the mean annual flow. The change point in drainage area size occurs where the MBF4 regression predicts this flow to occur, or at about 473 mi^2.

E.4 COMPARISON OF UPPER MBF AND LOWER MBF ALTERNATIVES WITH ALL DATA AND UPSTREAM PASSAGE FLOW REQUIREMENTS

Figure E-11 depicts the Upper MBF (MBF3) and Lower MBF (MBF4) alternatives with the collective spawning flow data compiled from other studies. The two relationships envelope most of the data for steelhead and coho and appear suitable for evaluation as alternatives defining a full range of protectiveness levels.

The MBF3 alternative is based on steelhead instream flow requirements that should also provide for Chinook spawning habitat in deeper water areas with suitable substrates and velocities, which appear to be the more critical parameters defining spawning site selection and success (DeVries 1997). There are a small number of tributaries to the Russian River that also provide critical habitat for Chinook, specifically including lower Austin Creek, lower Mark West Creek, Feliz Creek near Hopland, Mill Creek near Redwood Valley, and the upper Russian River above the East Fork Russian River. Chinook spawning habitat would also likely be protected in these streams by using the MBF3 alternative based on steelhead spawning criteria. It is anticipated that Chinook spawning habitat in the mainstem Russian River and Dry Creek will be mostly protected by flow releases from Warm Springs and Coyote Valley dams (Entrix 2002, 2004).

The magnitude of the MBF3 criterion for spawning appears sufficient to also ensure upstream passage in most cases, as indicated in Figure E-12. Albeit not under ideal passage conditions, the MBF3 alternative for spawning habitat recommends flows that generally still provide for steelhead and coho passage in small streams, and Chinook passage in large streams, which is consistent with their general distributions in the Policy area. This can be seen by comparing the MBF lines with minimum reported passage depth criteria for these three species which are, respectively: 0.5 ft, 0.33 ft, and 0.75 ft (Table G-3 in Appendix G). Even the MBF4 alternative is predicted to result in flows providing minimum passage depths of 0.5 ft for steelhead in riffles, and thus should also be regionally protective of upstream passage (Figure E-12).

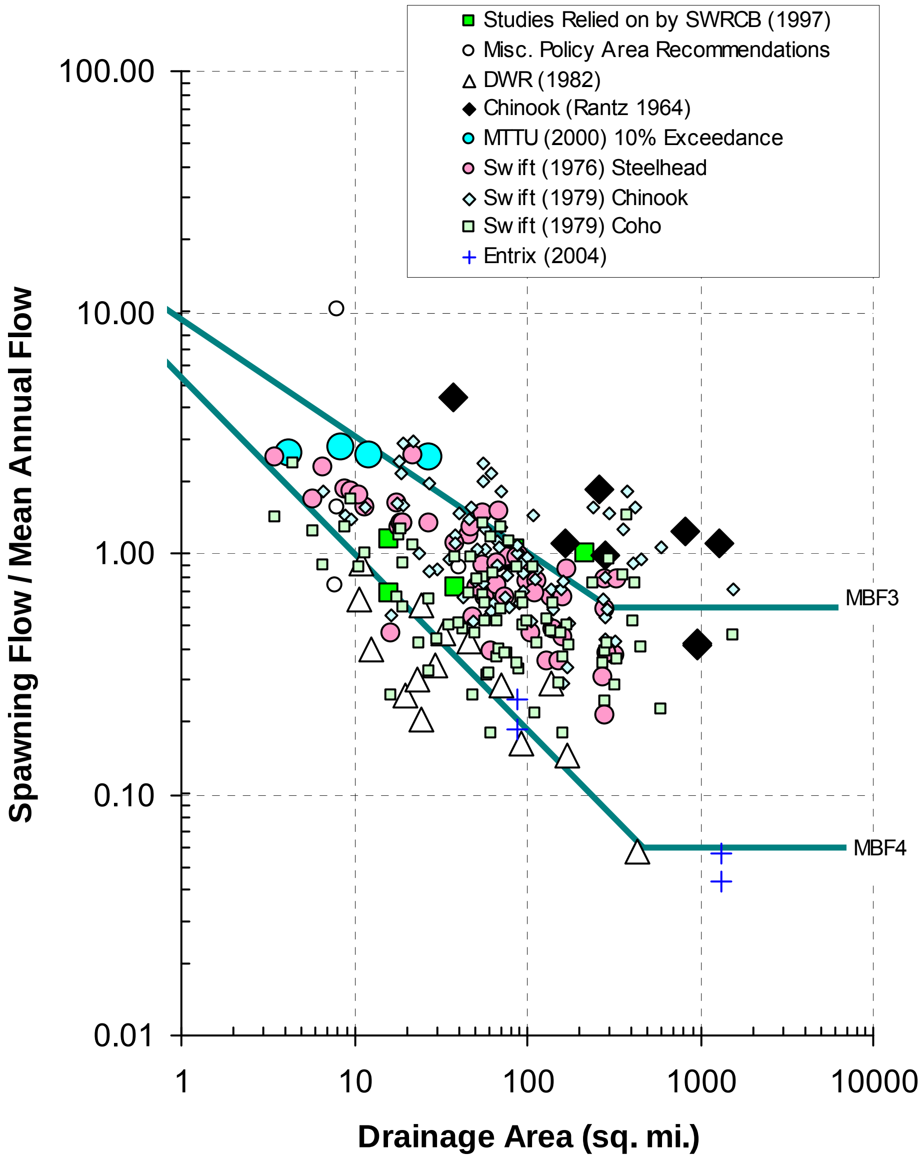

Figure E-11. Upper MBF (MBF3) and Lower MBF (MBF4) alternatives plotted with existing regional and local spawning habitat-flow data.

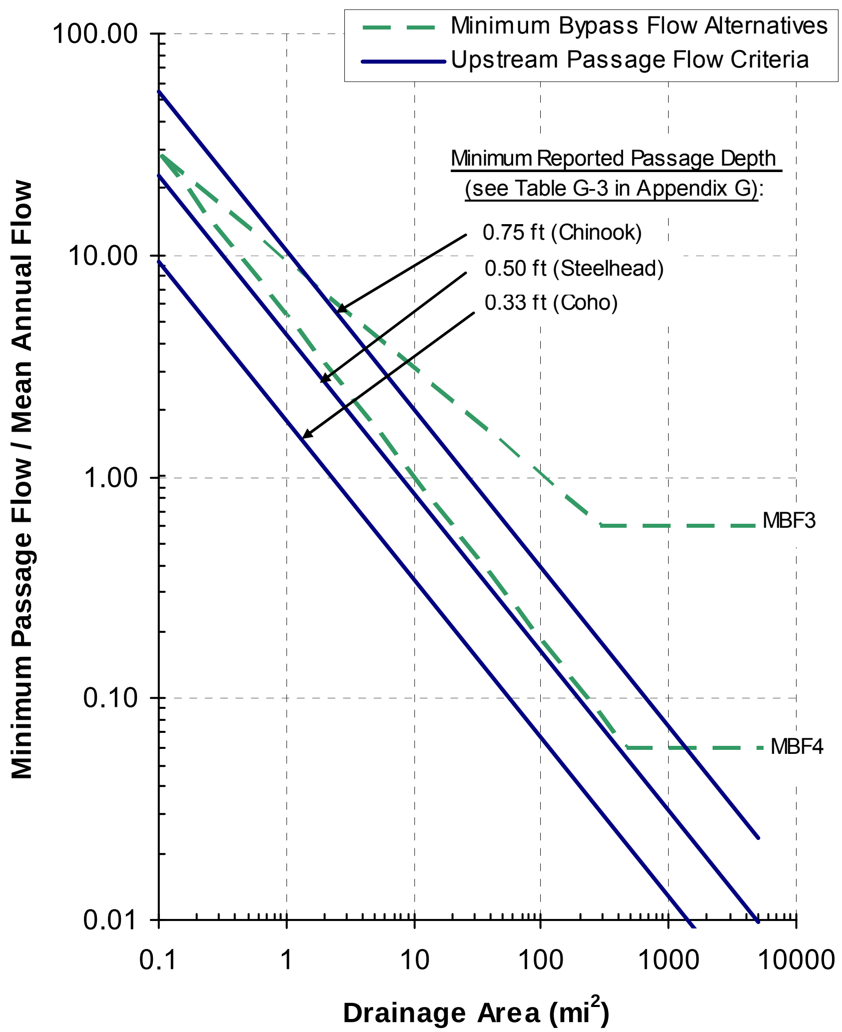

Figure E-12. Comparison of Upper MBF (MBF3; upper dashed line) and Lower MBF (MBF4; lower dashed line) alternatives with upstream passage flow criteria resulting from Equation (E.1) in streams where anadromous salmonids are present. Lines corresponding to specific minimum passage depth (MPD) criteria are indicated by arrows.

E.5 SUMMARY OF MINIMUM BYPASS FLOW ALTERNATIVES

Based on the above analysis and considerations, the Upper MBF (MBF3) alternative (Q_{MBF}) based on protecting spawning habitat and upstream passage is:

- Basin Area < 295 mi^2: $Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48}$ (E.11)
- Basin Area ≥ 295 mi^2: $Q_{MBF} = 0.6\ Q_m$
- Streams Above Anadromy Limit: $Q_{MBF} = 9.4\ Q_m\ (DA_2)^{-0.48}$

where DA_2 is evaluated at the upper limit of anadromy.

The Lower MBF (MBF4) alternative (Q_{MBF}) based on protecting spawning habitat and upstream passage is:

- Basin Area (DA) < 0.1 mi^2: $Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48}$
- Basin Area = 0.1-473 mi^2: $Q_{MBF} = 5.4\ Q_m\ (DA)^{-0.73}$ (E.12)
- Basin Area ≥ 473 mi^2: $Q_{MBF} = 0.06\ Q_m$
- Streams Above Anadromy Limit: $Q_{MBF} = 9.4\ Q_m\ (DA_2)^{-0.48}$. where $DA_2 < 0.1\ mi^2$
  or $Q_{MBF} = 5.4\ Q_m\ (DA_2)^{-0.73}$. where $DA_2 \geq 0.1\ mi^2$

where DA_2 is again evaluated at the upper limit of anadromy.

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