ECOLOGICALLY BASED SYSTEMS MANAGEMENT:

FINAL ANALYSIS AND RECOMMENDATIONS FOR SYSTEM RESTORATION

Evaluation of Flow Regimes, Aquatic Habitats, and Floodplain Vegetation

In the INTRODUCTION section of this report, we introduced 5 critical intervals of the annual discharge regime necessary for Ecologically Based Systems Management to address to restore the range of ecological function to the Snake River study area (see Figure 3). Each interval addresses specific ecological bottlenecks that directly or indirectly affect the Shifting Habitat Mosaic or the life histories of the organisms using these environments and habitats.

During the winter (Interval 1), the primary concern is winter aquatic habitat for native fish and by inference other native species that are pre-adapted to natural winter flow regimes of the Snake River. Prior to dam construction, dam operation and control of winter flows, the long-term average of discharge in mid-winter was approximately 2500 cfs (Figure 37). The minimum flows during winter for each day from December through March fluctuated between 1500 and 2000 cfs. Our analysis of aquatic habitats at these low flows revealed a comparatively high frequency of shallow low turbulent runs, shallow shore, and shallow near shore riffles (Figure 33 a-e). The frequency of these slower waters decrease, both in real terms and as a function of overall percentage of total aquatic habitat, as flows approach 5000 cfs (Figure 33).

Maintaining low flow habitat during cold water temperatures is particularly important as fishes seek to minimize activity as metabolic rates decrease and their ability to sustain position in rapidly moving waters diminishes. It is also important to maintain similar flow regimes throughout the winter period, rather than manipulate flows in response to anticipated high or low water volume (Figure 37), which addresses the issues highlighted in Interval 2 (see Figure 3).

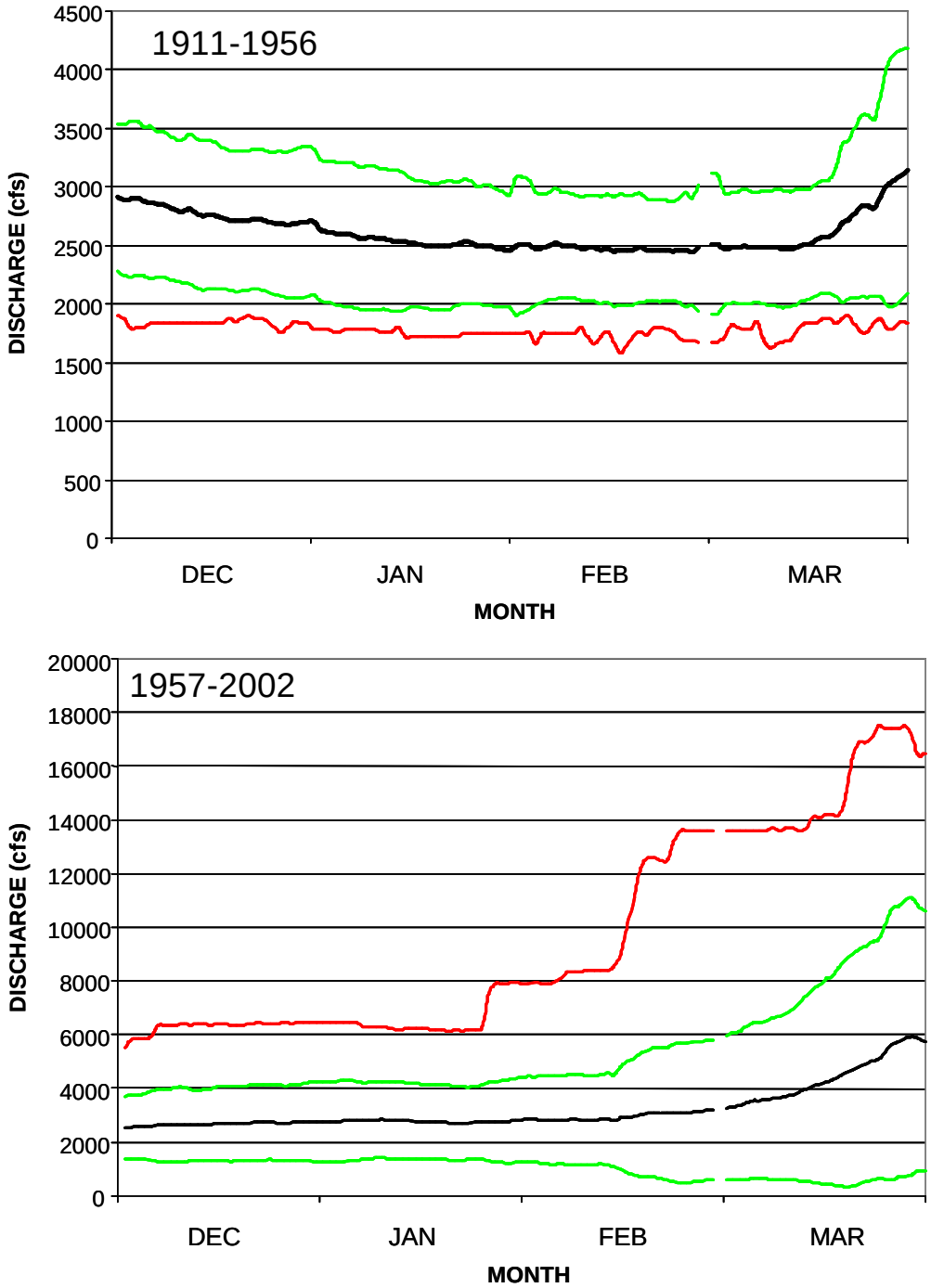

Figure 37. Upper panel represents the pre-dam winter hydrograph; the lower panel is the winter hydrograph since dam operations began in 1957. Black lines are the mean discharges, green lines are the standard deviation. In the upper panel the red line is the minimum daily discharge for the period of record pre-dam; the red line in the lower panel is the maximum daily discharge post-dam.

Early reservoir draw-down has resulted in significant change in the flow regimes of the Snake River in many years with flows in mid-winter often reaching 5000 to 6000 cfs. The maximum winter discharge illustrated in Figure 37 shows discharges increasing as early as late January and exceeding 10,000 cfs by mid-February. This is, with all likelihood, very deleterious to the fishery and other organisms associated with the aquatic habitats of the Snake River in the study area. Response to reservoir water volumes and anticipated should be addressed during the natural spring freshet period, which typically began in the pre-dam period after April 1.

In sections above, we discussed the minimum geomorphic threshold discharge levels necessary to initiate mobilization of the gravel/cobble bed-sediments of the floodplains in the study area. This and the duration of those flows are the focus of Interval 3 (Figure 3). Geomorphic work not only depends on the peak flows and the exceedance of threshold discharges, but also depends on the duration of these discharges, and thus, the length of time over which work is done. Costa and O'Connor (1979) demonstrated that for some stream systems in the Cascade Mountains, extreme discharges of short duration did not do significant amounts of geomorphic work compared to lower level discharges that were maintained over much longer durations. They concluded that this was mainly a characteristic of well vegetated floodplains exposed to flashy discharge regimes (e.g., climatically event driven spates of high peak discharge but very short duration).

In order to address the duration factor, we examined the relationship between discharge and total cumulative power applied to the floodplain. We determined the relationship of discharge to cumulative power for approximately 1000 cfs increments from 1500 to 37,000 cfs for the Fisher floodplain (Figure 38). We then used a best-fit, third-degree polynomial regression

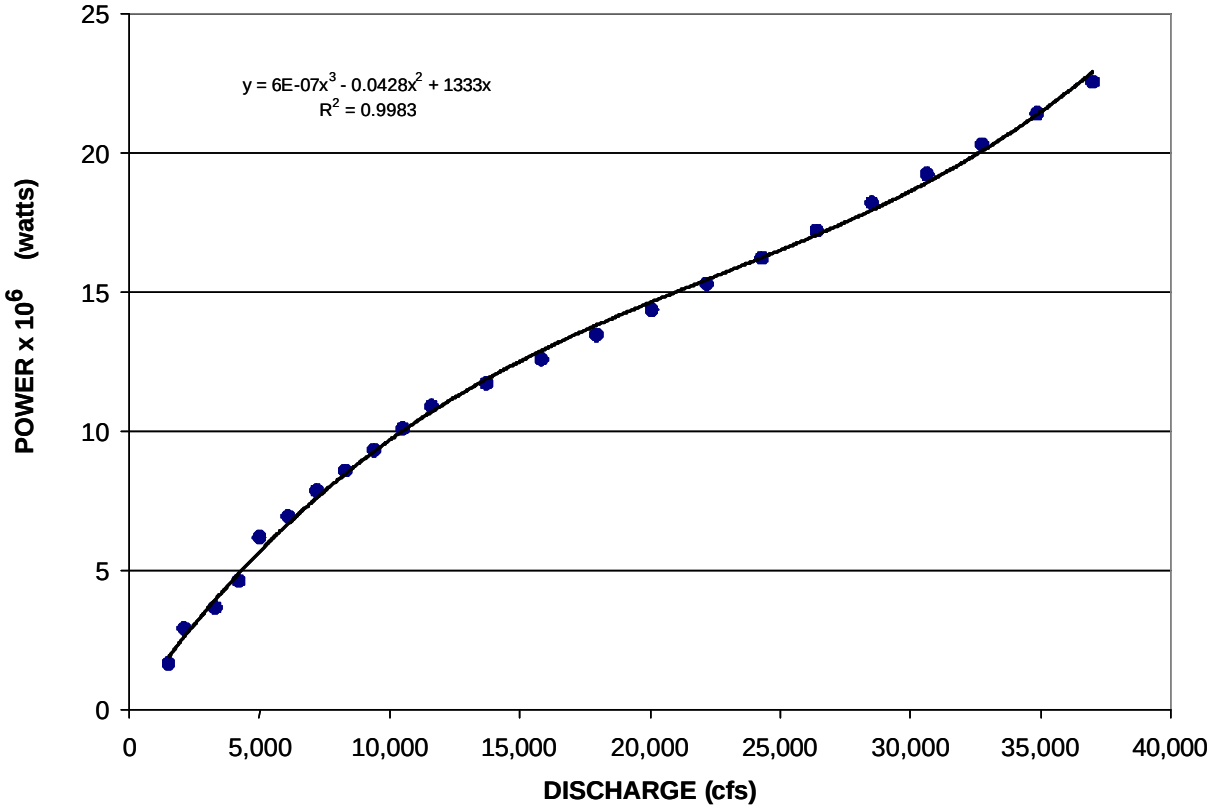

Figure 38. The relationship between discharge and total available stream power acting on the Fisher floodplain. Data are derived from the hyperspectral imagery, modeling of depth and velocity and the determination of river power across discharge regime from 1000 to 37,000 cfs.

equation to correlate stream power across discharges:

$$Y = 6 \times 10^{-7}x^3 - 0.0428x^2 + 1333 \qquad r^2 = 0.99 \qquad (5)$$

Based on our earlier analysis of the discharges necessary for Parafluvial avulsion, we estimated daily power for the Fisher floodplain comparing the annual distribution of power for various historical discharge events as discharge exceeded 19,000 cfs. We selected 19,000 cfs as this is the average threshold discharge to initiate Parafluvial avulsions. We selected the 10 water years with the highest total annual discharge prior to dam construction and applied the power analysis for each of the 10 years (Figure 39). We compared these data to 10 water years with the highest total annual discharge after dam construction and applied the power analysis for each of the years (Figure 39). Although total volume of water in the before dam and after dam years were similar, there was a significant reduction in power available to do geomorphic work in the after-dam years (Figure 39). Clearly, this is mainly due to the reduction of both peak flow and duration of flows exceeding 19,000 cfs as flood control strategies that have been integral to the management practices and general operation of Palisades dam.

The following power analysis examines how duration of the annual flood volume of water can be used to maximize the available stream power to do the geomorphic work. We compared the total annual cumulative power when 19,000 cfs is achieved or exceeded among each of the 20 highest discharge volume water years prior to dam operation (Figure 40; black data points) with the 10 largest flood years for the dam operation after 1957 (Figure 40; blue data points) [Note: these are the cumulative power data as appear in Figure 39, but with 20 years covered before the dam].

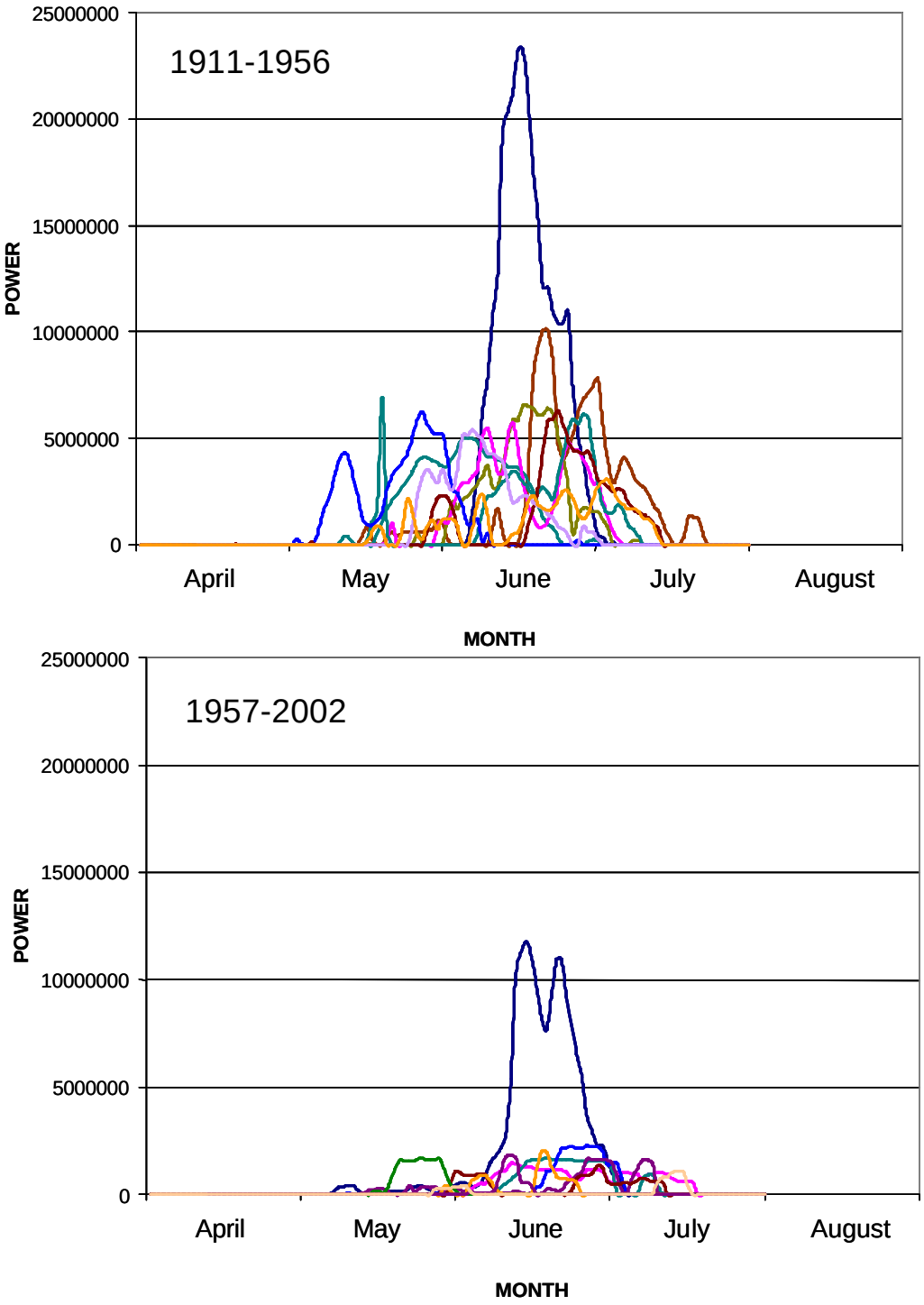

Figure 39. Upper panel illustrates the total daily power (total watts/floodplain) on the Fisher floodplain for the 10 highest water years prior to dam operations; the lower panel illustrates the comparative data for the 10 highest water years post-dam.

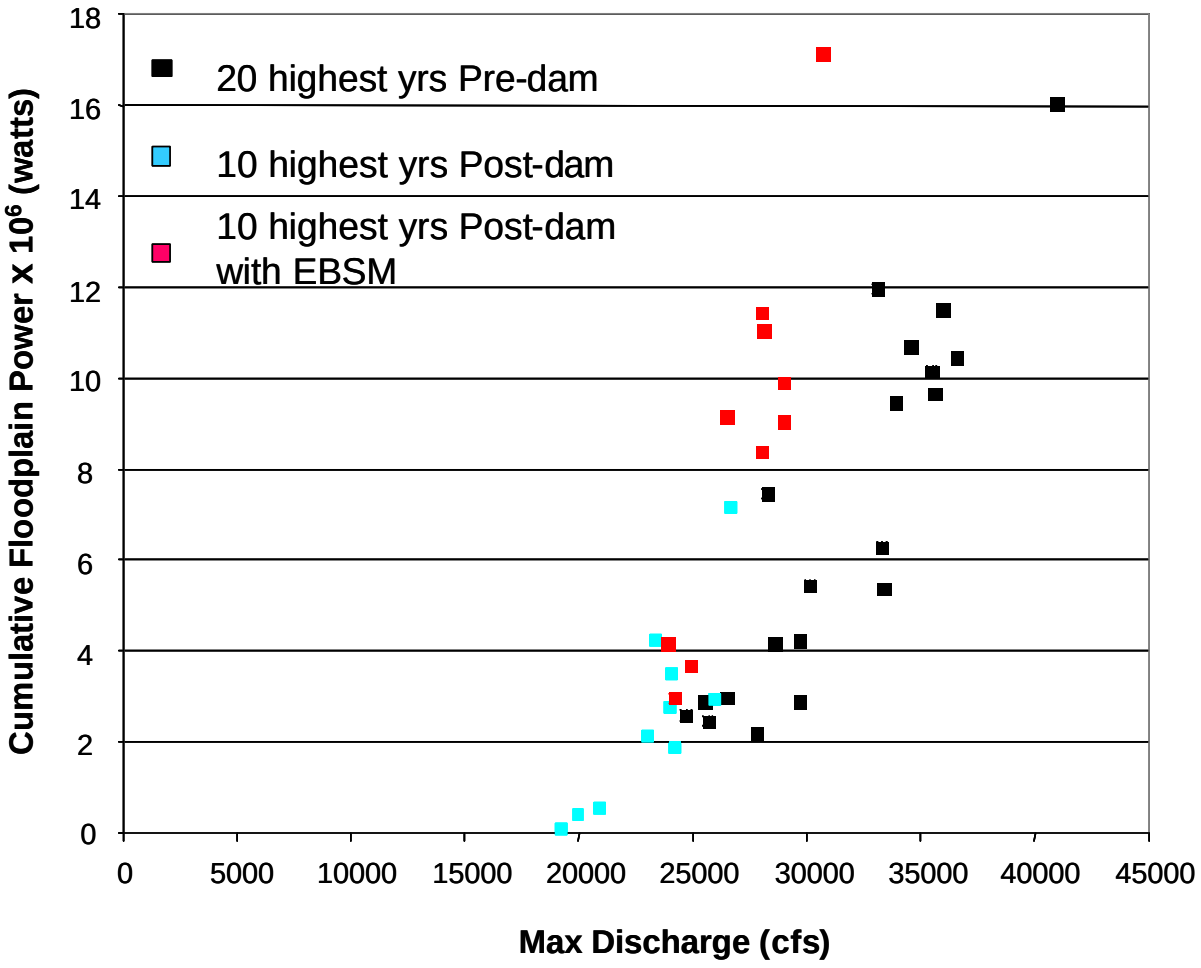

Figure 40. Cumulative annual power (watts/floodplain) on the Fisher floodplain for the 20 years of the highest water volume discharge prior to dam construction (black data points), for 10 years of the highest water volume discharge after dam construction (light blue data points, and for 10 years of the highest water volume discharge after dam construction with Ecologically Based System Management discharge scenarios applied to the annual hydrographic regime

Recall from our earlier analyses above that peak discharge among post-dam years (except for 1997) have remained under 30,000 cfs with annual cumulative power between 2 and 4 x 10^6 watts. Also as discussed above among post-dam water years, peak discharge in very wet years achieved the highest maximum discharges only approaching the 28,000 cfs threshold that is required for Orthofluvial avulsion events. Also note that the 28,000 cfs is a *threshold* for the potential to initiate Orthofluvial avulsions across all the study floodplains. A 34,000 cfs discharge level is required to achieve the *highest* potential for Orthofluvial avulsion, which has never been achieved but once since dam construction (1997). In contrast, there were 7 pre-dam years (1911-1956) that achieved or nearly achieved the 34,000 cfs, where the highest potential for Orthofluvial geomorphic work is obtained. On the Fisher floodplain these high and sustained discharges generate annual cumulative power between 9 and 12 x 10^6 watts (Figure 40). This likely represents an approximate level of *THRESHOLD CUMULATIVE POWER*, adjusted for floodplain area, necessary to achieve the Orthofluvial avulsions for all the floodplains in the study area.

To more fully address the issue of peak flow and duration of flow, we further evaluated the flow regimes of the 10 high discharge volume years post-dam assessed above in Figure 40 [blue data points]. To accomplish this we adjusted the spring discharges occurring before April 1 (i.e., as addressed above in Figure 3 - Interval 2) to be discharged during the natural spring freshet. The results of these analyses are that power to do geomorphic work could be significantly increased above threshold levels and the cumulative power necessary to sustain Parafluvial avulsions were easily achieved and that Orthofluvial avulsion could be realized without having to release or sustain discharges above 30,000 cfs (Figure 40; red data points). To reiterate; in this illustration of the data (Figure 40), the post-dam high water volume years and the power they derived are expressed as blue data points. The same water years with EBSM

adjusted discharge regimes (which we discuss and illustrate in detail below), using the same volume of water, generate power to do geomorphic work illustrated by the red data points. By making these adjustments to the discharge regime in Palisades operations, the Snake River achieves discharges in wet and moderately wet years that group between 9 and 12 x 10^6 watts, similar to the power generated in wet years prior to dam operations (Figure 40; black data points). We believe that this is a central issue in the EBSM flow regimes and critical to the restoration and sustainability of the Snake River Shifting Habitat Mosaic and the organisms that are dependant on its dynamics.

Intervals 4 and 5 of Figure 3 are focused on the rate of the descending limb of the hydrograph after peak discharge and the sustaining of water volume throughout the summer. These issues are important ecologically and are central to the contractual obligations of Reclamation and the operating license of Palisades dam. Peak discharges typically occur throughout the Rocky Mountain big rivers (e.g., Snake, Yellowstone, Flathead, Bitterroot) in May and June as snow melts in the higher elevations of the mountains. The high discharges discussed above are not only important for the transport of sediments, but are important for the deposition of new surfaces that can be colonized by cottonwood seedlings. Natural discharges that occurred in the Snake River prior to dam construction and that occur elsewhere among unregulated river in the region, typically have descending hydrographs that do not exceed rates of approximately 5% per day. This rate of discharge decline allows the cottonwood seedlings that have germinated on newly formed sediment surfaces during the high flows to grow tap roots that are capable of maintaining capillary contact with the descending water table on the floodplain. In our EBSM discharge scenarios, not only are river power thresholds achieved, but there is sufficient water volume to maintain the appropriate rate of decline.

A major concern of the agricultural community and irrigators using Snake River water is that high discharge in June (in order to do geomorphic work), followed by a 5% decline in the hydrograph (to sustain cottonwood regeneration) will result in depleted water reserves for irrigation late in the summer. However, with the EBSM scenarios that we present below, late summer water volumes are maintained at or above that which was realized the year from which these scenarios were developed.

Working Scenarios of EBSM River Discharge Regimes

The following approach is based on the analysis of river power, aquatic habitat availability across discharges, and the life history dynamics of the native flora and fauna (as we understand them) of the Snake River in the study area. As we pointed out earlier in this report, there are competing interests vying for the water resources of the Snake River below Palisades dam. While some studies have suggested that regular river discharges as high as 40 - 60,000 cfs may be necessary to reestablish the regeneration of the cottonwood forest, the agriculture community desires to retain as much water for irrigation in summer as possible and the US Army Corps of Engineers is concerned about flood control. Furthermore, over the past several years winter discharges have been highly variable from year to year and within years, again as a function of competing interests, in winter usually between fisheries concerns and irrigators risk. In very wet years, high discharges have been the rule of operation during winter and spring to capture an anticipated runoff and to eliminate risk of flooding. These various competing interests have been generally based on single species *foci* or single management interests and have in general lead to a river system that has been compromised in its ecosystem scale ecological integrity.

We present here a series of post-dam water years illustrating the discharge regime as it occurred and an example of an Ecologically Based Systems Management scenario discharge regime that meets the various criteria for an ecosystem level restoration of Snake River ecological integrity. For illustration here, we selected a wet year, a moderately wet year and dry year to demonstrate the concepts and viability of this approach to river restoration. Each scenario uses the volume of water discharged that year and reshapes the hydrograph the meet ecological criteria within each of the temporal Intervals given in Figure 3. The determination and fine adjustment of these criteria would not have been possible without the application of the technological tools and analyses that we explain in the RESULTS section above.

The first EBSM scenario we have selected is a high water volume year, 1996. That year increased discharge from the dam was initiated in anticipation of high spring snowmelt in mid-February (Figure 41; black line). Maximum discharge in the river occurred in mid-June and the falling hydrograph met the operating criteria and contractual obligations for irrigation water of the Palisades project. Following the criteria of EBSM, we adjusted the existing water volume by maintaining low flow throughout the winter (Figure 41; red line). We increased discharge only after April 1, at a rate not to exceed 10% per day. Given the water volume available, we elected to increase the discharge to achieve the 19,000 cfs Parafluvial geomorphic work threshold rather than the lower discharges that were actually realized that year (i.e., 15,000 to 18,000 cfs). As water volume in the reservoir increased in mid-June, we increased discharge to more than 28,000 cfs and sustained that discharge as long as possible and still meet the descending hydrographic criteria for cottonwood seedling regeneration and irrigation needs. Along the descending limb of the hydrograph, we followed the criteria of not decreasing daily mean discharge at a rate greater

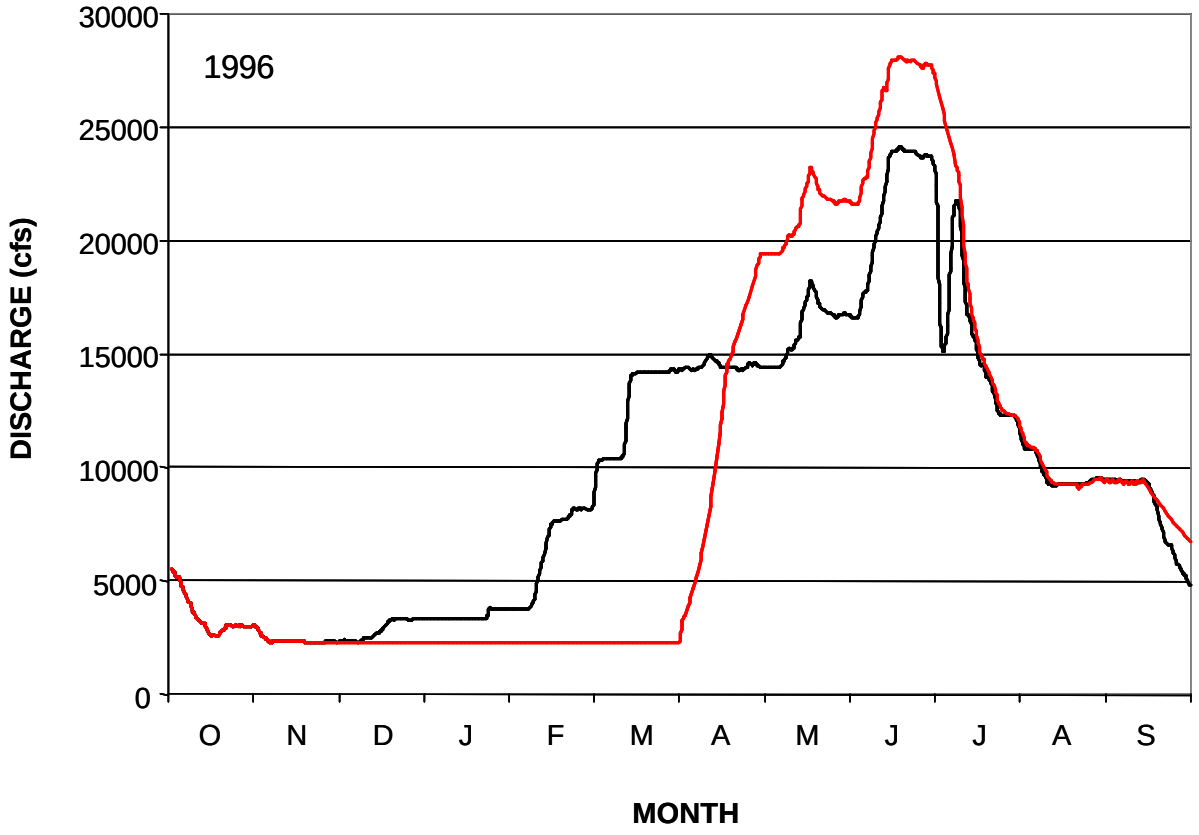

Figure 41. Illustration of the 1996 realized mean daily discharge (USGS Heise) in the wet, high water volume discharge year 1996 (black line). The red line represents an example of applying Ecologically Based Systems Management to reshape the hydrographic regime an meet the ecological criteria of re-engaging the river and floodplain system to restore the processes associated with the Shifting Habitat Mosaic. The corresponding power analysis revealed a >2X increase in geomorphic work being done in the EBSM scenario hydrograph.

than 5% per day. We also maintained the scenario discharge at or just above the realized discharge that year throughout the summer; thus meeting irrigation requirements.

In the second EBSM scenario, the water volume is representative of a moderately wet year, 1999 (Figure 42; black line). We followed the same criteria as expressed above for the 1996 EBSM scenario. In the realized discharge of that year, high discharge was initiated in February and continued into March and April. Maximum discharge in 1999 exceeded 19,000 cfs for only a few days. In the EBSM scenario, we kept water level at the December discharge regime throughout the winter and into April (Figure 42; red line). We allowed the river to increase in discharge at a rate not exceeding 10% until it achieved a level similar to the realized discharge. The realized discharge regime was tracked until mid-June when we increased peak discharge to approach 30,000 cfs. This was maintained for several days and then allowed to decrease at a rate not to exceed 5% per day. We also tracked the rates of decline in the hydrograph to simulate the realized hydrograph. It is clear from this illustration that higher summer discharges were continued throughout most of the summer, thus more than meeting the irrigation and operation requirements of the Palisades project.

In our final example scenario we have chosen to illustrate a dry water year, 2000 (Figure 43). We followed the same criteria as expressed above. However, in keeping with the adaptive management character of the EBSM approach, there is insufficient water volume to achieve high discharges and river power. This should be expected in dry periods and are not dissimilar from the discharge regimes that occurred naturally in dry years in the Snake River study area pre-dam.

Note that in wet and moderately wet water years the EBSM discharge criteria and resulting scenarios remain below the 1997 flood maximum. This is an important consideration in the EBSM approach. Extremely high water years, like 1997, will be realized again in the

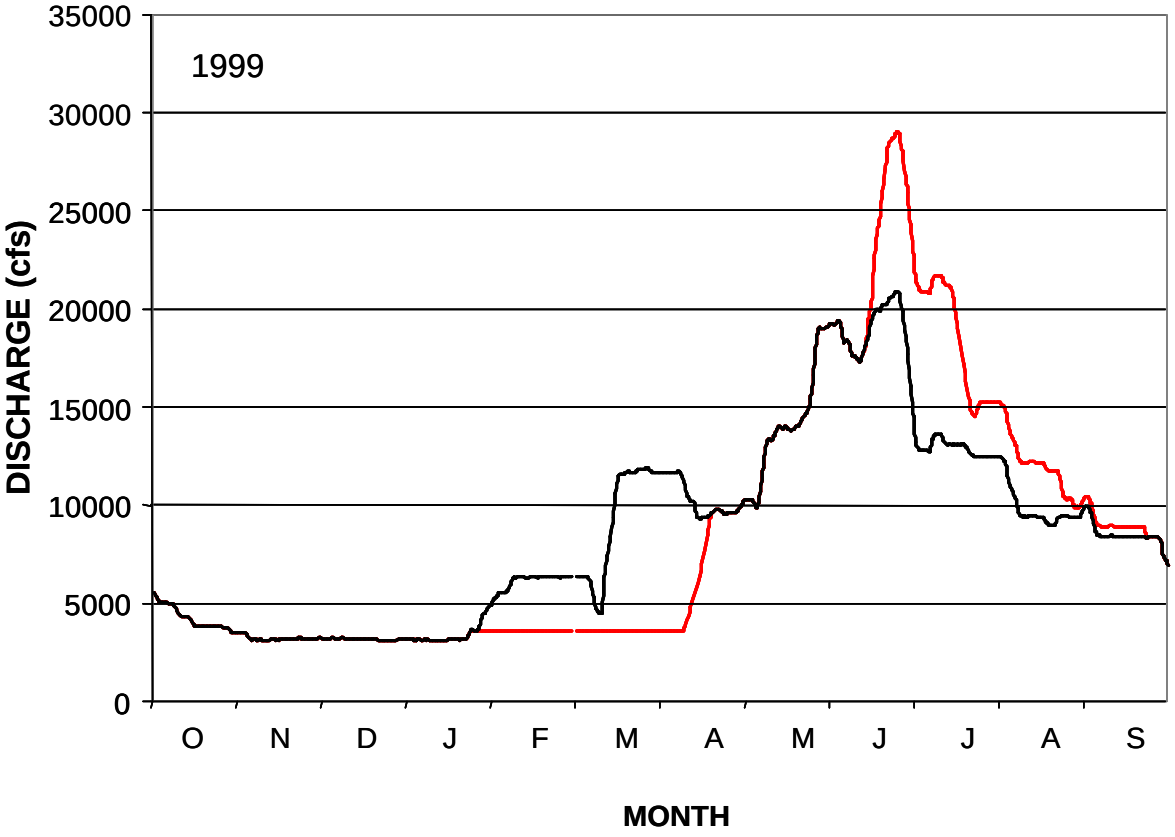

Figure 42. Illustration of the 1999 realized mean daily discharge (USGS Heise) in the moderately wet water volume discharge year (black line). The red line represents an example of applying Ecologically Based Systems Management to reshape the hydrographic regime an meet the ecological criteria of re-engaging the river and floodplain system to restore the processes associated with the Shifting Habitat Mosaic. The corresponding power analysis revealed a >5X increase in geomorphic work being done in the EBSM scenario hydrograph.

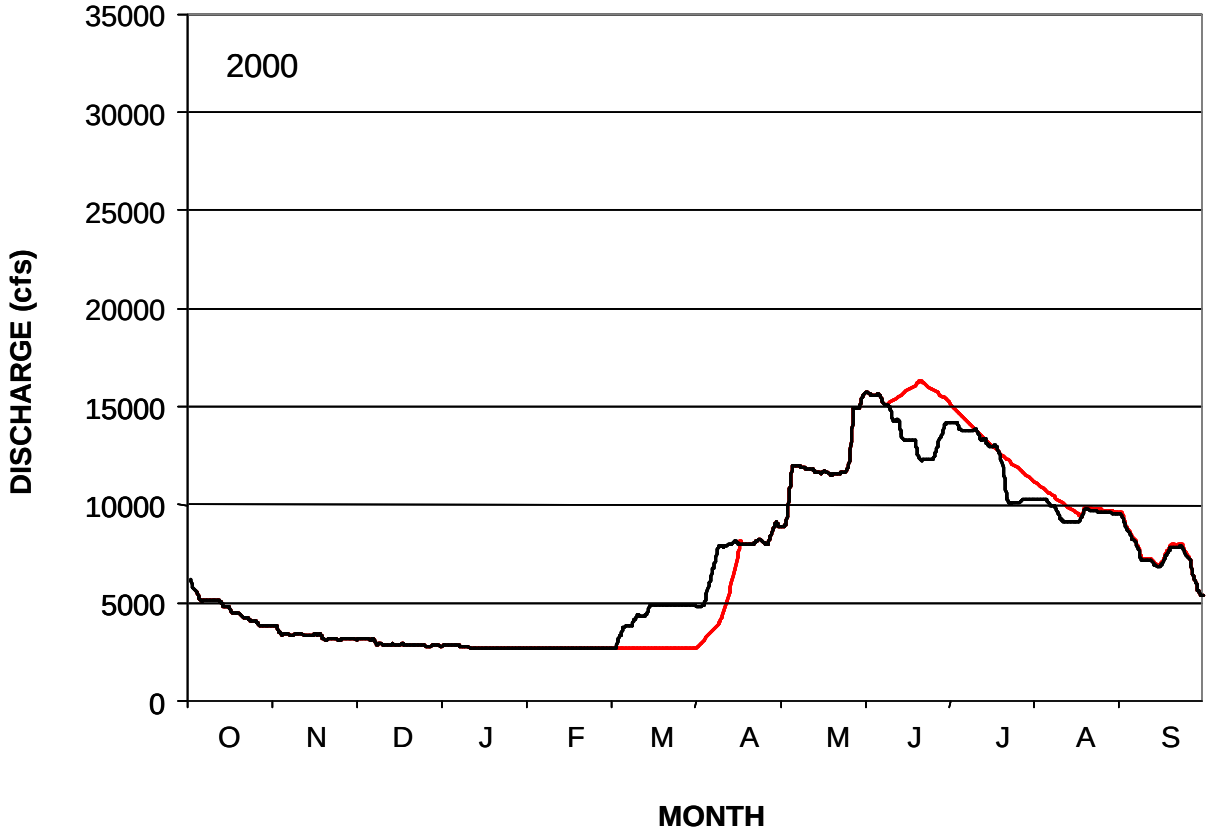

Figure 43. Illustration of the 2000 realized mean daily discharge (USGS Heise) in the dry, low water volume discharge year (black line). The red line represents an example of applying Ecologically Based Systems Management to reshape the hydrographic regime. Without water volume stored or being delivered in dry years, it is appropriate to follow past protocols that our analysis showed are not dissimilar to the natural hydrographic regimes occurring in dry year prior to dam construction.

future. To believe otherwise is to ignore the range of variation in water yield that Rocky Mountain watersheds are capable of generating. The EBSM scenarios do not generate discharges greater than an already established discharge benchmark in the wettest year since dam construction.

The restoration and long-term ecological sustainability of ecosystem structure and function in the Snake River below Palisades dam is dependant on the dynamics of a Shifting Habitat Mosaic. Systems management has the opportunity to reengage the river and its floodplain by implementing the criteria that generated the EBSM scenarios discussed above. However, we must caution not only the Reclamation, but also the US Army Corps of Engineers, state and local government and the citizens of eastern Idaho, that floodplains that are re-engaged by following the EBSM Decision Support System and the criteria outlined herein can still loose ecosystem function and the Shifting Habitat Mosaic by permitting geomorphic modification (i.e., levees, rip-rap, groins, rock bar-points) or construction encroachment (i.e., homes, cabins, roads) onto the floodplain with their accompanying protective structures.