Summary of Results from GCDAMP TWG Multi-Attribute Evaluation Workshop

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1.0 Background and Purpose

This project was initiated as a result of a desire by the Glen Canyon Dam Adaptive Management Program (GCDAMP) to develop a framework for evaluating management actions and experiments. In May of 2003, a subset of the Technical Working Group (TWG) participated in a workshop to develop and test a multi-attribute trade-off analysis (MATA) approach. Members of the TWG who participated in the workshop supported the approach and recommended a second workshop with broader participation of TWG members.

GCMRC is now in the process of updating its science/experimental program for 2004. To assist in that process, the TWG conducted a two-day workshop in December 2003 to evaluate options using the MATA framework that was piloted in May. The objectives of the workshop were:

- To demonstrate and refine the MATA framework for evaluating management options
- To expose key trade-offs and uncertainties among management options
- To provide input on experimental priorities for the coming 5-10 years.

At the workshop, participants reviewed and refined the endpoints (resource outcomes of concern) and the attributes (quantitative metrics for assessing the impact of the management options on the endpoints). They then identified management options and estimated the impact of each option on each attribute. Key uncertainties and trade-offs were identified and discussed. Participants were then asked to complete a questionnaire to elicit from them both a direct ranking of options and a weighting of attributes. While there was not enough time to review the results in detail, some high-level messages were reviewed and the implications for experimental priorities were briefly discussed.

The intent of the workshop was to identify the options with the most potential to deliver acceptable long term solutions. These options would then be candidates for experimental treatments designed to reduce uncertainties about their effects. Thirty-one TWG members, GCRMC staff and other observers participated in the workshop (Appendix A).

This report summarizes the endpoints and attributes, the options, the consequence table that was produced at the workshop, the results of the ranking and weighting exercise, preliminary implications for management, and proposed next steps.

2.0 Endpoints, Attributes, Options and Consequences

The refined endpoints and attributes are summarized in Table 1. TWG members defined and evaluated twelve management options:

1. **MLFF**: Modified low fluctuating flows with ramping constraints as employed during the 1990s, with no policy options for protection/restoration of humpback chub; beach habitat building flows (BHBF) only permitted following regulatory spills from GCD.

2. **SASF**. Seasonal adjusted steady flows intended to mimic natural hydrograph as closely as practical (spring peaks, winter minima); no diurnal flow fluctuation, and no other measures for HBC protection/restoration. BHBF only permitted following regulatory spills from GCD.

3. POWER (**P**). Flows from GCD set for optimal power production (load following), with 3k-30k diurnal range over entire year (similar to mid 1980s flows). No measures for HBC protection. BHBF only permitted following regulatory spills from GCD.

4. **MLFF+FSF+BHBF**. Modified low fluctuating flows as 1990s during Jan-August, followed by fall (Sept.-Dec.) low steady (or slowly declining) flows without diurnal fluctuation. Followed in January by BHBF in years when steady flow period has resulted in significant accumulation of sediments from summer tributary sediment inputs.

5. **P+FSF+BHBF**. Load following diurnal flows (3-30K cfs) during Jan-Aug, followed by low steady flows (FSF as in option 4) and Jan BHBF in years of significant tributary sediment input.

6. **P+MLFF+FSF+BHBF**. Similar to option 5, except load following flows permitted only January-May, followed by low modified fluctuating flows (MLFF) over the summer period prior to fall steady flow period and BHBF (aimed primarily to improve recreational boating conditions during peak summer use period).

7. **P+BHBF Anytime**. Similar to option 3 (load following all year, 3-30K diurnal variation), but with beach habitat building flows permitted at any time deemed optimum for sand retention in the system (e.g., following major tributary sediment inputs).

8. **P+TCD8**. Similar to option 3(load following all year, 3-30K diurnal variation), but with temperature control device for all eight GCD turbines to provide minimum summer GCD outflow temperature of 15.C. No BHBF specified except as opportunity arises through regulatory releases.

9. **P+TCD8+MECH**. Similar to option 8 (power production by load following 3-30K, TCD installed for all eight GCD turbines) but including mechanical removal program (electrofishing, netting, etc) to control development of warmwater exotic predators (striped bass, catfish, carp, etc.).

10. **P+SF/BHBF+TCD8+MECH**. Load following power flows Jan-May (3-30K cfs) followed by low steady (or slowly decreasing but no diurnal fluctuation) flows to Dec and Jan BHBF if sediment inputs permit. Temperature control device on all eight GCD turbines, mechanical removal as in option 9 to prevent warm water exotic fish responses to temperature increase.

11. **P+FSF/BHBF+TCD8+TURB**. Load following power flows (3-30K cfs) Jan.-Aug., followed by low steady flows September-December and BHBF in January. Temperature control device on all eight GCD turbines. Turbidity increased seasonally from Paria River whenever it is not naturally turbid over the summer and fall (June-November), by mechanical sediment inputs, to disadvantage visual exotic predators.

12. **Power+MECH**. Load following power flows (3-30K cfs) all year, accompanied by mechanical removal program (as 2003) for control of exotic cold water fish predators in LCR reach.

The impact of each management option on each attribute was then estimated (Table 2). In assigning the consequences, the emphasis was on the accuracy of relative scores (across options), rather than absolute values. However, an attempt was made to bound the range from worst and best (see reference points associated with worst and best in Table 1).

Table 1 Endpoints and Attributes

Endpoint	Attribute	Description
NATIVE FISH – HUMPBACK CHUB	MS – P Establish	Reports the probability of establishing a viable population of humpback chub in the mainstem Colorado River
	LCR – EU - P Ex - P Same - P Healthy	Reports the effect of an option on chub abundance in the Little Colorado River. The summary indictor EU is the expected utility of an option as a function of its "risk profile" for LCR chub abundance. The risk profile is defined by assuming that for each option there are only three possible outcomes for chub abundance: P Ex is the probability of extirpation, P Same is the probability that there will be no change from current; and P Healthy is the probability of a return to healthy population size. The EU reports the utility or value of the resulting risk profile, assuming standard values for risk aversion (i.e., avoiding a loss is more valuable than realizing an equivalent gain).
SPORT FISH – RAINBOW TROUT	Abundance (thousands)	Reports expected abundance of rainbow trout > 150 mm in reach above Lees Ferry.
	Size (pounds)	Reports average expected size of rainbow trout above Lees Ferry
	Probability of Collapse (%)	Reports the probability that the abundance of rainbow trout above Lees Ferry will decline by 50% or more.
SAND DEPOSITION	Trend in Storage (slope)	The slope of change in total sand storage over a 10 yr period. A negative value indicates more sand is being exported than is being retained. A positive value indicates an accumulation of sediment.
	Total Sand Area above 25 kcfs	The area of sand above 25 kcfs relative to the amount present in 1984. This represents the amount of sand available for Aeolian transport, campsites, and potential marsh development. *In theory, this effect is covered by other attributes (e.g., historic properties and campsite availability.*
CULTURAL/ RIPARIAN	Marshes and SWFC Habitat	An index of the number and area of marshes and SWFC habitat relative to its maximum potential as indexed by conditions in 1984. Frequent disturbances (BHBFs) with regular wetting maximize this endpoint (1 = maximum, corresponding to the maximum potential in 1984: 0 = minimum, corresponding to no potential for marsh development).
	LRZ Vegetated Beach Area	An index of the biomass and diversity of vegetation present on eddy sand bar deposits. The endpoint will increase with the amount of sand bar area and the frequency of floods. (0 is the minimum, corresponding to 1984; 1 not defined.)
	Historic Properties	This endpoint could not be fully defined without discussion with tribal TWG members. In its current state, the endpoint indexes the amount of dry sand that would be available for aeolian deposition at archeological sites.

Endpoint	Attribute	Description
RECREATION	Probability of Incident	Reports the expected percentage of commercial and private trips on which bodily injury will occur or equipment damages will be in excess of $500. Bodily injury includes potential infections associated with elevated water temperatures from the TCD.
	Canyon Campsite Availability	This index tracks the availability of campsites relative to the 1984 condition (i.e., a score of 1.0 indicates the 1984 condition. A score of 0.3 (current condition) indicates 30% of the 1984 condition. The endpoints responds to sand area above 25 kcfs, the frequency of floods which remove vegetation, and the daily flow range which limits the availability of existing beaches.
	LF Trout User-days	The number of user-days relative to 20,000, the assumed usage of the mid 1990's (e.g., a score of 1.2 indicates 1.2 x 20,000). This index responds to the size and abundance of rainbow trout as well as fishing conditions determined by dam operations.
	Powell Boat Access	A flag which determines whether boat ramps in Lake Powell will be accessible between Memorial and Labor days. This flag is largely determined by the overall storage level in Lake Powell. Increased releases during low storage could trigger this flag. 0 is off (no concern); 1 is on (potential concern).
POWER / FINANCIAL	WAPA Power Cost (average annual cost in million $/yr)	Reports the average annual cost of a management option relative to ROD operations (i.e., options with net savings relative to ROD are reported as negative numbers). These are the costs to WAPA; they do not reflect distribution of costs to WAPA customers, nor do they include costs to taxpayers. Costs of BHBF releases are based on an assumed frequency of 1 in 5 yrs.
	Other Costs (levelized annual cost in million $/yr)	Reports the levelized annual cost of non-power options such as TCD and other works. These are costs that are covered by appropriation and are incurred by taxpayers rather than WAPA.
WILDLIFE	Peregrine Falcon	An index of aquatic productivity in the mainstem that ultimately determines the abundance of prey (mostly ducks) for peregrine falcons. This index applies to the river upstream of the LCR. The index is primarily driven by water transparency which limits autotrophic production. (A score of 1= best, corresponding to current conditions where several hundred pairs can be supported, and 0 is worst corresponding to insufficient aquatic productivity to support peregrine falcons)
	Kanab Amber Snail	An index of the proportion of KAS habitat available, relative to the amount present in 1995 prior to the 1996 flood (1 = maximum availability, corresponding to 1995 habitat availability. All other values are scaled from 1; i.e., 0.2 indicates that 20% of the 1995 habitat is expected to be available.) This index responds to moderate floods as well as high flows at maximum powerplant capacity. About 40% of the KAS pop is affected.
	Low Riparian Zone Channel Margin Area	A 0-1 index describing the biomass of vegetation on channel margin deposits, which forms the majority of wildlife habitat in Grand Canyon. (1=best, corresponding to the 1995 margin area; a score of 0.5 indicates half the area is available.)

Table 2 Estimated Impacts of the Options on the Attributes

		Alternatives											
		1	2	3	4	5	6	7	8	9	10	11	12
Attribute	**Units**	**MLFF**	**SASF**	**P**	**MLFF + FSF + BHBF**	**P + FSF+ BHBF**	**P + MLFF+ FSF+ BHBF**	**P+ BHBF Anytime**	**P + TCD8**	**P + TCD8 + MECH**	**P+ SF/BH +TCD8 +MECH**	**P+ FSF/BH +TCD8 +TURB**	**P + MECH**
NATIVE FISH - HBC													
MS Chub - P Establish	%	0%	5%	0%	0%	0%	0%	0%	20%	25%	30%	30%	0%
LCR Chub - EU	utility units	0.79	0.72	0.80	0.80	0.80	0.80	0.80	0.68	0.87	0.91	0.68	0.86
- P Extirp	%	10%	20%	10%	10%	10%	10%	10%	25%	5%	3%	25%	5%
- P Same	%	80%	60%	75%	70%	70%	70%	75%	50%	50%	40%	50%	60%
- P Healthy	%	10%	20%	15%	20%	20%	20%	15%	25%	45%	57%	25%	35%
SPORT FISH - RAINBOW TROUT													
Abundance	Abundance; 1 =100,000	1.00	1.30	0.30	1.00	0.30	0.80	0.25	0.30	0.30	1.10	0.30	0.30
Size	pounds	0.40	0.30	1.20	0.40	1.20	0.50	1.20	1.50	1.50	0.35	1.50	1.20
Probability of Major Decline	%	10%	10%	10%	10%	10%	10%	10%	20%	20%	20%	20%	10%
CULTURAL													
Marshes and SWFC in Marble Canyon (15-20	0-1 index	0.50	0.60	0.65	0.75	0.80	0.75	0.80	0.65	0.65	0.80	0.75	0.65
LRZ Vegetated Beach Area	0-1 index	0.40	0.40	0.50	0.60	0.60	0.60	0.65	0.50	0.50	0.60	0.60	0.50
Historic properties (arch sites)	% of 1984	50%	60%	40%	70%	65%	65%	70%	40%	40%	75%	60%	40%
SAND DEPOSITION													
Trend in Storage	slope	-1.00	-1.00	-0.75	0.00	0.10	0.10	0.50	-0.75	-0.75	0.30	0.10	-0.75
Total Sand Area above 25kcfs	% of 1984	50%	50%	60%	70%	80%	80%	90%	60%	60%	80%	80%	60%
RECREATION													
Probability of Incident	% of trips	5%	5%	10%	5%	10%	5%	15%	20%	20%	25%	25%	10%
Campsite Availability	Index; 0.3=current	0.30	0.30	0.15	0.45	0.35	0.40	0.40	0.15	0.15	0.60	0.50	0.15
LF Trout User Days	Index: 1=20,000 user days	1.00	0.80	1.00	0.95	0.95	0.95	0.95	1.20	1.20	1.00	1.20	1.00
Powell Boat Access	1=flag	0	0	0	1	1	1	0	0	0	1	1	0
FINANCIAL IMPACT													
Direct power improvement	Million $/year; 0=ROD	0.0	-85.0	50.0	-10.4	22.9	6.3	49.2	50.0	50.0	-33.7	22.9	50.0
Mitigation $ impact (TCD etc.)	Million $/year	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-6.4	-7.4	-7.4	-7.4	-1.0
WILDLIFE													
Peregrine Falcon Abundance (food web)	Index; 1=sev hundred pairs	0.80	0.90	0.50	0.80	0.60	0.80	0.65	0.45	0.45	0.65	0.30	0.50
Kanab amber snail	Index; 1=1995 level	0.80	0.90	0.60	0.20	0.20	0.20	0.20	0.60	0.60	0.20	0.20	0.60
Low Riparian Zone Channel Margin Area	Index; 1=1995 level	0.20	0.10	0.30	0.50	0.70	0.50	0.70	0.30	0.30	0.65	0.65	0.30

3.0 Ranking and Weighting Exercises

After a review of the consequence table, stakeholders participated in a structured values elicitation process. There are three main reasons to use structured methods to elicit stakeholder values and preferences:

- to increase the accuracy and consistency of individual stakeholder judgments;
- to provide focus for constructive deliberations and refinement of the options;
- to increase the accountability and transparency of decisions by making the trade-offs made by stakeholders explicit.

The purpose is not to prescribe an answer. The goal of decision modeling, as in ecological modeling, is to provide insight as an aid to decision making. Stakeholders are still responsible for making difficult value based trade-offs and choices.

There are many ways to elicit values. Different methods usually produce different results; no method is necessarily right. The use of multiple methods provides insight to the decision by thinking about it in different ways. By examining choices from different perspectives, stakeholders will have more confidence that their choices reflect their values, and are not the result of methodological bias.

In this exercise, we used two methods: a) Direct Ranking and b) Swing Weighting. In Direct Ranking, stakeholders were asked to rank and then score each management option directly, based on a review of the consequence table. In swing weighting, they were asked to rank and weight each attribute. The term "swing" weighting is used because decision makers are asked to say which attribute they would most want to "swing-up" from its worst to its best value. This is important because in some cases an attribute may be important in a general sense, but the actual change in the attribute value that results from the choice among management options may be relatively insignificant (i.e., it is not particularly sensitive to the option set); this should affect the weight assigned to it, as we are weighting the importance we assign to the attribute in this specific decision context.

For swing weighting, attribute weights are entered into the following equation that computes an overall score for each option:

$$SCORE(a) = W_1(x_{1a}) + W_2(x_{2a}) + \ldots\ldots$$

Where:

SCORE(a)	= the calculated score for a management option (e.g. 'a')
W_1, W_2...	= the weight of an attribute
x_1, x_2...	= the scaled impact of a given option on each attribute

Ranks for each management option for each stakeholder are then derived.

The ranking and weighting questionnaires are shown in Appendix C.

4.0 Ranking and Weighting Results

Due to time constraints, there was very limited discussion about the consequence table and the trade-offs among options prior to completion of the questionnaire. As a result, caution should be used in interpreting the results. It is likely that different participants interpreted the options, the attributes and the attribute scores differently, leading to inconsistencies in ranking and weighting. Further there was no opportunity for group discussion about the significance of a shift in attribute scores across options for any given endpoint, nor any opportunity for value-based discussion about the relative importance across endpoints. Therefore, the TWG should consider this a preliminary exercise and the beginning, rather than the conclusion, of a constructive deliberative process. The following summary is provided for discussion purposes.

Figure 1 compares ranks assigned by the direct method and ranks assigned by the swing weighting method for one example stakeholder. This format for presenting results is intended to aid individual stakeholders in improving the thoroughness and consistency in their choices. (With more time, each stakeholder would receive his/her individual results at the workshop.) Options ranked the same by both methods fall on or near the 45 degree line. Options that fall far from the 45 degree line should trigger a re-examination of that option by the stakeholder. For example, from Figure 1 we see that stakeholder TWG 3's ranks are quite consistent across the two methods for most options (differences in ranks of 1 or 2 places are not very significant). However, Option 7: P + BHBF Anytime ranked fairly low by the direct method, but is ranked number one by the weighted method. On the other hand, Options 11 and 9 ranked high by the direct method and low by swing weighting. While these discrepancies do not necessarily mean that the direct rank is wrong, they may indicate any of a number of problems, such as:

- mixing up the options or misunderstanding the definition of the options in the direct ranking (common when there are many options);
- overlooking some elements of performance in the direct ranking (common when there are many attributes);
- overlooking options that are less controversial or less visible (reflecting a tendency to spend more discussion time on options with either vocal champions or vocal opponents).

Alternatively the direct ranking may be a more accurate reflection of the stakeholder's values if the attributes do not adequately capture all the important elements of performance (e.g., missing attributes, hidden thresholds, competing unidentified hypotheses). The intent of the multi-method approach is therefore not to say that one method is better than another, but to expose inconsistencies, clarify the rationale for choices, and improve the transparency and accountability of decisions.

Across all stakeholders, options that frequently fell below the 45 degree line (while being direct-ranked in the top six) were 9 and 11. Options frequently falling above the 45 degree line (while being ranked in the top six by swing weights) included Options 7 and 6, and to a lesser extent 5 and 10.

Figure 1 Comparison of Ranks by Direct and by Swing Weighting Methods for TWG 3

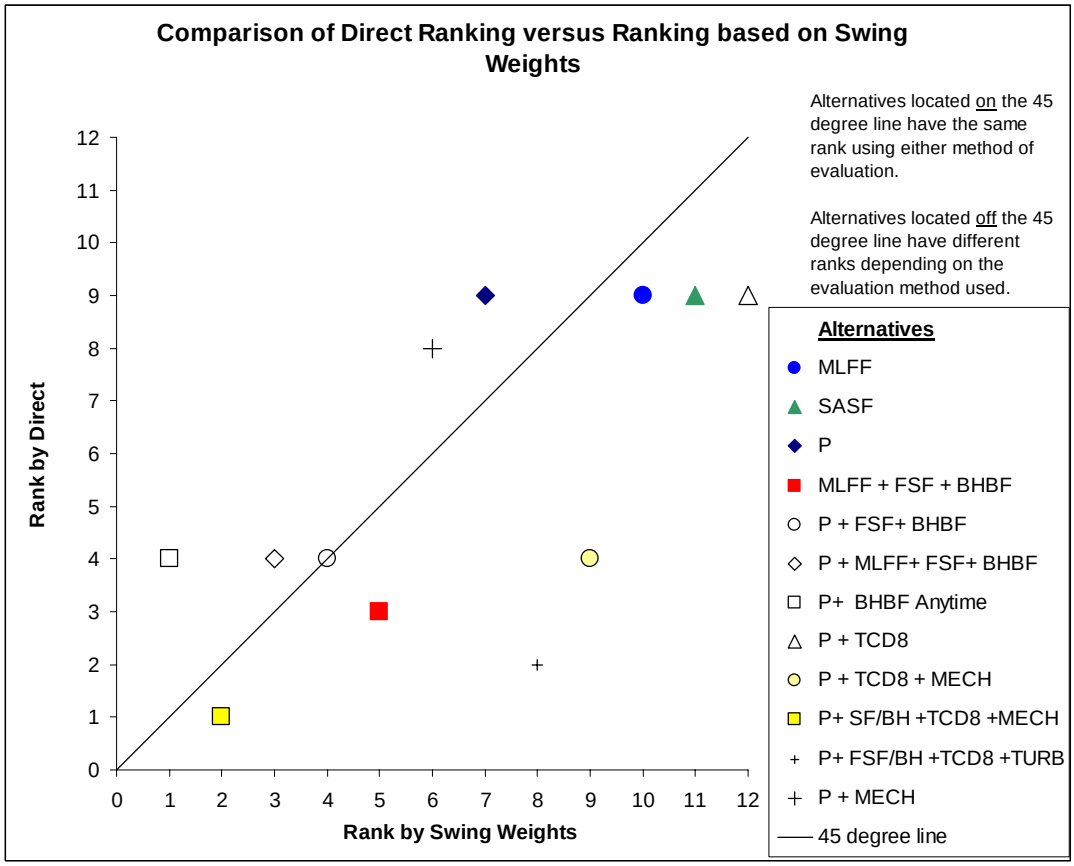


Figure 2 shows the range and distribution of weights assigned to each attribute by the group of stakeholders. It is a function of both the lower level weight assigned to each attribute within an endpoint category, and the weight assigned to the endpoint category. Figure 3 shows the weights assigned to the endpoint categories. Without the benefit of dialogue about these values, it is difficult to draw any conclusions from them. Some observations:

- At the higher level (endpoint) level, Chub and Sand Deposition consistently weighted high.
- At the attribute level, Lake Powell Access and LF Trout User Days consistently weighted low.
- Some weighted the very large financial impact to power lower than the small financial impact to taxpayers.
- There are significant differences in relative weights assigned to rainbow trout abundance versus size; this seems like something that should be resolved by trout/guide user groups rather than TWG as a whole.
- There are significant differences in assigned weights (e.g., ranging from 0 to about 25%) on cultural sites, wildlife and recreation. However, it is not yet clear without discussion whether these are due to true value differences or differences in interpretation of the attributes, the attribute scores or the weighting instructions.
- It is not clear to what extent participants considered resource values from a societal perspective, or from the perspective of their constituency alone.
- Participants need to review the imputed weights for individual attributes as a check on the weighting process.

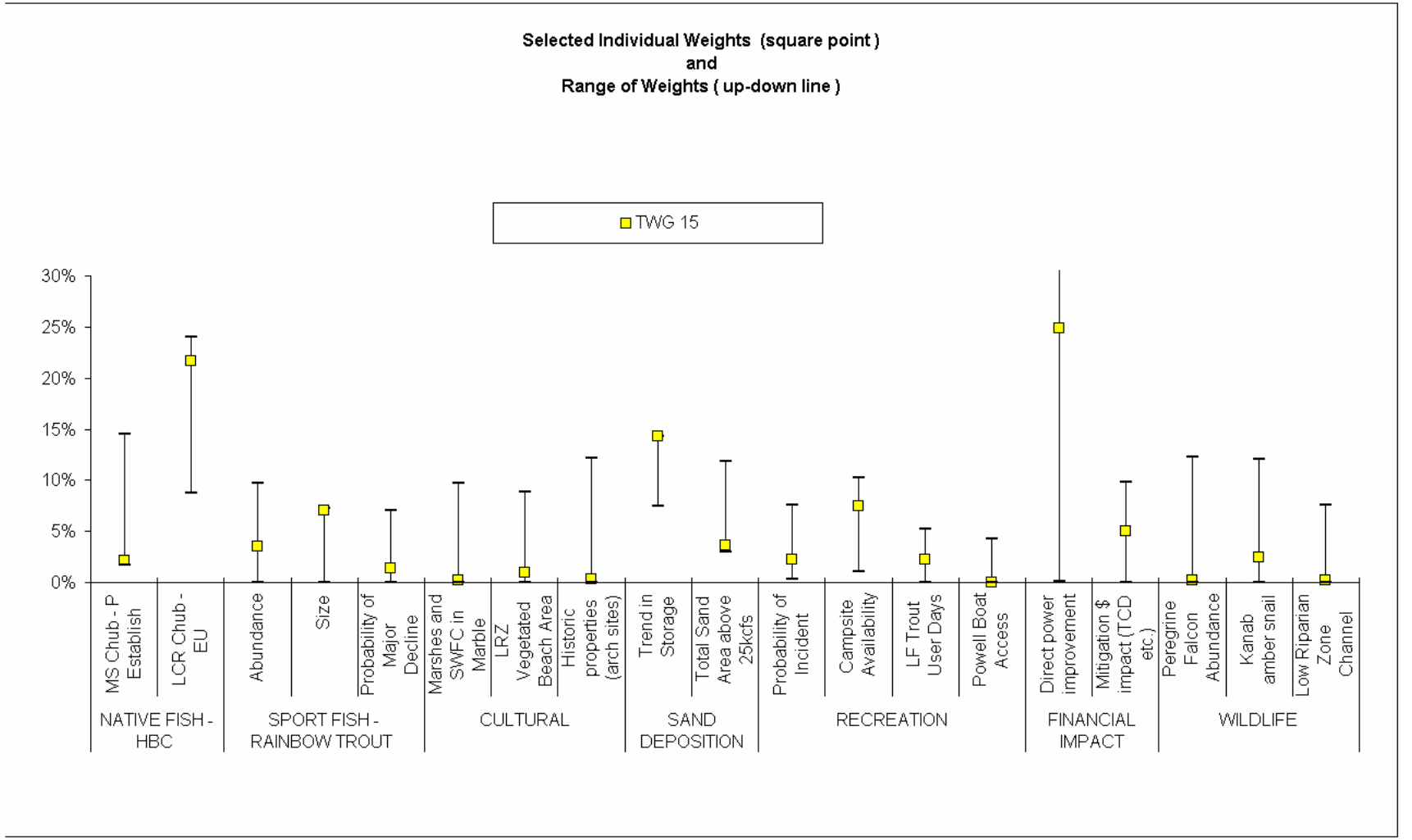


Figure 2 Attribute Weights

Figure 3 Higher level weights

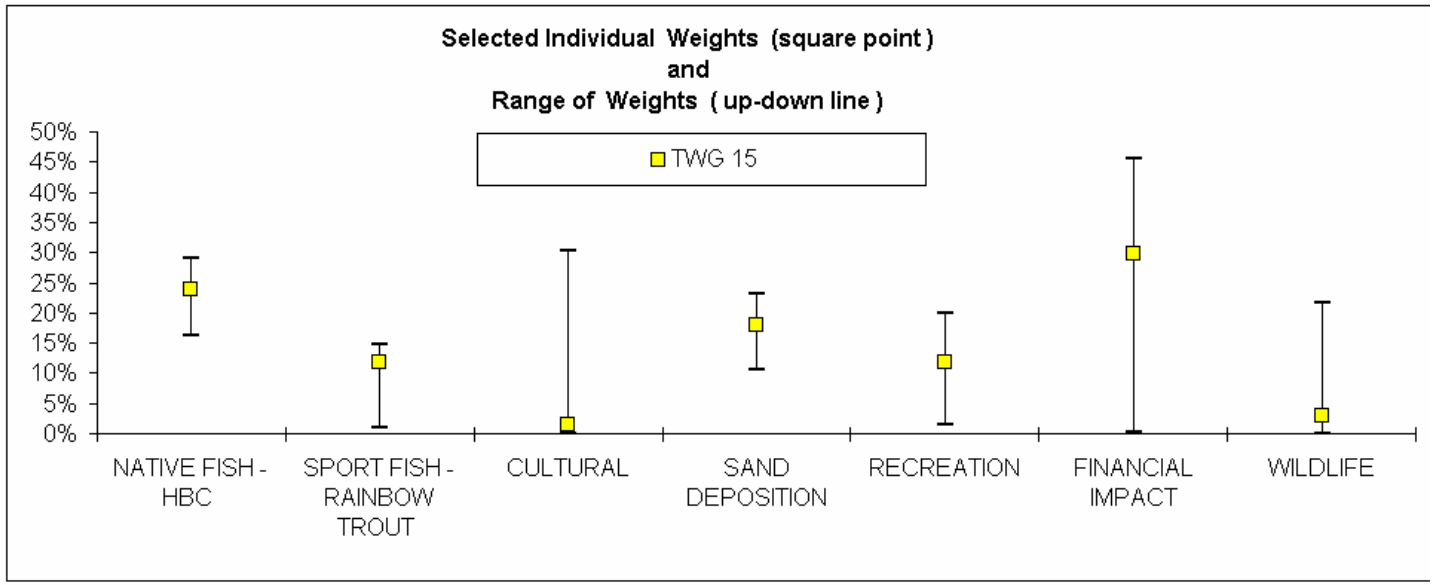


Figure 4 and Figure 5 summarize the ranks assigned by stakeholders to each option by the Direct and Swing Weighting methods respectively. For each stakeholder, options ranked 1 through 3 are colored blue, 4 through 6 are yellow, 7 through 9 are white, and 10 through 12 are red. Be aware that there are some boundary problems with this approach; in some cases calculated scores show very little different in the value of two options, but if one is ranked 3rd and another 4th they are assigned different colors, potentially exaggerating differences in value.

Overall, options 7 and 10 appear to be the strongest candidates. No participants liked Options 1 or 2 by either the direct or swing weighted methods. While options 4, 8, 9 and 11 have quite a bit of support in direct ranking, they do not score well by weights.

On the basis of these results, the TWG may want to consider eliminating Options 1 and 2 (MLFF and SASF) from further consideration.

Some alternatives are dominated or nearly dominated by others, and the TWG may want to consider eliminating them from further consideration as well:

- Option 3 (P) is dominated by 12 (P+Mech) for nearly all stakeholders by both methods (exception is TWG 13 who slightly prefers P by Direct and TWG 14 who slightly prefers P by Swing Weighting). See Table 1 in Appendix D for a direct comparison of these two options. The trade-off to consider is quite simple: a loss of $1.0 million per year in mitigation costs for a gain in LCR Chub EU (i.e., a reduction in the probability of extinction from 10 to 5%).

- Option 8 (P+TCD8) is dominated by 9 (P+TCD8+Mech) by both methods for nearly all stakeholders. See Table 2 in Appendix D. Again, the key trade-off to consider is the mitigation cost versus the gain for LCR Chub.

On swing weights, Option 4 (MLFF+FSF+BHBF) is dominated by 6 (P+ MLFF+FSF+BHBF); however several participants preferred 4 by direct ranks. Further consideration could be given to whether option 4 can be eliminated. However, there are complicated performance trade-offs involving Chub, Rainbow, Cultural Sites, Sand Deposition, Recreation and Costs. See Table 3 in Appendix D.

Options 7 and 10 (BHBF Anytime and P+SF/BH+TCD8+Mech) consistently performed higher by swing weighting than they did by direct ranks, suggesting that they may merit further consideration. Options 9 and 11 consistently under-performed by swing weights relative to direct ranks, suggesting that some participants may have anchored on these alternatives, without adequate review of the estimated performance (or that some aspect of performance is not captured – e.g., a missing attribute, a hidden threshold effect, unidentified competing hypotheses).

5.0 Next Steps and Outstanding Issues

The proposed next step is to review and refine the consequence table, the options and the attributes, to have some dialogue about the relative importance assigned to each attribute, and to repeat the weighting exercise.

Some questions the TWG should consider include:

- Which options can be eliminated? 1, 2, 3, 4 and 8 may be candidates for elimination.

- Should some new options be added or existing ones refined? One logical refinement would be to add BHBF to all options. In addition, the exact definition of some options (e.g., power) should be clarified; it was not clear that all participants had a common understanding.

- Are there attributes that can be eliminated or refined? For example, is the Lake Powell attribute useful in discriminating among the options? Could a subgroup of river/fishing guides agree on the relative importance of trout size and abundance?

- Is the relationship between the attributes and the endpoint and the relationships among the attributes clear and consistently interpreted across TWG members? For example, what is the relationship between Sand Deposition (total sand area above 25 kcfs) and the attributes for Historical Sites and Campsite Availability? What is the relationship between the rainbow trout abundance and size attributes, and the LF Trout User Days attribute? It may be preferable to eliminate some attributes; as a minimum, it is important to make sure all participants had a common understanding of what they were weighting.

- Are TWG members comfortable with the imputed weights for individual attributes? This is an important cross check on the weighting process.

- What is the cause of the differences in weights assigned to attributes across participants? In some cases these may be the result of real value differences. In others, due to time limitations in conducting the exercise, the differences may be caused by different interpretations of the attributes and their scores, and even the weighting instructions (e.g., did everyone consider the swing from worst to best; did they understand the mathematical relationship between the points allocation and the weights?)

- Can members representing the same constituency agree on a common set of weights/responses?

- Are TWG members satisfied with the attribute scores in the consequence table? Given the speed with which the exercise was conducted, a final check for consistency in the assignment of scores across alternatives is warranted. In addition, some participants expressed concern at the workshop that all the uncertainties had not been fully discussed. Where these uncertainties are affecting agreement about the options, further discussion about the support for competing hypotheses may be warranted to either increase confidence in the assigned scores, refine the scores, or refine research and experimental priorities.

Figure 4 Ranks Assigned to Alternatives by All Stakeholders by Direct Ranking

		1	2	3	4	5	6	7	8	9	10	11	12
	Method	MLFF	SASF	P	MLFF + FSF + BHBF	P + FSF+ BHBF	P + MLFF+ FSF+ BHBF	P+ BHBF Anytime	P + TCD8	P + TCD8 + MECH	P+ SF/BH +TCD8 +MECH	P+ FSF/BH +TCD8 +TURB	P + MECH
TWG 1	Direct	10	8	11	1	5	4	6	8	7	2	3	11
TWG 2	Direct	8	7	8	4	6	2	3	8	8	1	5	8
TWG 3	Direct	9	9	9	3	4	4	4	9	4	1	2	8
TWG 4	Direct	11	10	11	6	3	6	2	8	3	1	5	9
TWG 5	Direct	9	9	8	2	6	4	2	9	7	1	5	9
TWG 6	Direct	9	12	2	10	7	8	3	5	4	11	6	1
TWG 7	Direct	8	8	12	5	8	5	7	4	2	1	2	8
TWG 8	Direct	11	12	3	9	2	10	1	4	5	7	8	6
TWG 9	Direct	11	10	11	5	5	5	5	4	3	1	2	9
TWG 10	Direct	8	7	5	9	6	4	1	11	11	2	3	10
TWG 11	Direct	5	5	8	8	8	8	8	4	3	1	2	5
TWG 12	Direct	10	10	10	7	5	4	5	7	2	2	1	9
TWG 13	Direct	10	10	9	3	6	5	1	7	7	2	4	10
TWG 14	Direct	11	12	8	9	3	4	1	9	6	5	2	6
TWG 15	Direct	8	9	1	9	6	7	5	3	3	9	9	1
TWG 16	Direct	9	12	5	11	7	8	3	2	1	10	6	4
TWG 17	Direct	12	11	10	7	5	8	1	5	4	2	3	9
NON-TWG 1	Direct	12	11	9	8	6	7	5	4	2	1	3	10
NON-TWG 2	Direct	11	12	6	8	2	5	1	6	8	4	3	10
NON-TWG 3	Direct	12	10	11	5	3	4	2	9	7	1	6	8
NON-TWG 4	Direct	12	8	11	8	6	4	2	7	5	3	1	10

Figure 5 Ranks Assigned to Alternatives by All Stakeholders by Swing Weighting

	Method	MLFF	SASF	P	MLFF + FSF + BHBF	P + FSF+ BHBF	P + MLFF+ FSF+ BHBF	P+ BHBF Anytime	P + TCD8	P + TCD8 + MECH	P+ SF/BH +TCD8 +MECH	P+ FSF/BH +TCD8 +TURB	P + MECH
TWG 1	Swing	10	11	9	5	4	3	2	12	8	1	6	7
TWG 2	Swing	11	12	9	5	4	3	2	10	7	1	6	8
TWG 3	Swing	10	11	7	5	4	3	1	12	9	2	8	6
TWG 4	Swing	11	9	10	4	5	3	2	12	7	1	6	8
TWG 5	Swing	11	12	9	5	3	4	2	10	7	1	6	8
TWG 6	Swing	11	12	5	10	6	7	1	9	2	4	8	3
TWG 7	Swing	11	10	9	5	4	3	2	12	7	1	6	8
TWG 8	Swing	10	12	7	5	2	3	1	11	8	4	9	6
TWG 9	Swing	10	12	9	5	3	4	1	11	7	2	6	8
TWG 10	Swing	11	10	8	5	3	4	1	12	9	2	6	7
TWG 11	Swing	12	9	11	7	6	5	2	10	4	1	3	8
TWG 12	Swing	11	12	9	6	3	4	2	10	7	1	5	8
TWG 13	Swing	11	10	9	5	4	3	2	12	8	1	6	7
TWG 14	Swing	10	8	11	4	5	3	2	12	7	1	6	9
TWG 15	Swing	10	12	7	8	2	6	1	11	5	3	9	4
TWG 16	Swing	10	12	8	5	2	3	1	11	9	4	6	7
TWG 17	Swing	11	12	9	5	3	4	1	10	7	2	6	8
NON-TWG 1	Swing	10	11	9	5	3	4	1	12	8	2	6	7
NON-TWG 2	Swing	11	12	9	5	3	4	1	10	7	2	6	8
NON-TWG 3	Swing	11	12	9	5	3	4	2	10	7	1	6	8
NON-TWG 4	Swing	10	11	9	4	5	3	2	12	7	1	6	8

Appendix A Participants

Barbara Ralston	GCMRC
Ted Melis	GCMRC
Randy Seaholm	CWCB
Bill Persons	AZGFD
Larry Stevens	GCMC
Denny Fenn	GCMRC
Jan Balsom	GRCA
Jeff Cross	GRCA
Glen Knowles	FWS
John Ritenour	GLCA
Dave Garrett	M3 Research
Pam Garrett	M3 Research
Pam Hyde	GCWC
Gary Burton	WAPA
Glark Burbidge	WAPA
Leslie James	CREDA
Chris Updike	NAU
Dave Harpman	Reclamation
Jeff English	FFF
Lloyd Greiner	CREDA
Norm Henderson	NPS/SLC
Lew Coggins	GCMRC
Mike Yeatts	Hopi Tribe
Wayne Cook	Upper Colorado River Comm (states)
Lisa Force	Grand Canyon Trust
Helen Farley	GCMRC
Dennis Kubly	Reclamation
Randy Peterson	Reclamation
Andre Potochnik	Grand Canyon River Guides
Matt Kaplinski	GCRG
Clayton Palmer	WAPA

Appendix B HBC Risk Profiles and Expected Utility

Given the uncertainty in the response of chub to any option, it was estimated probabilistically. For each option, it was assumed that there are three possible and discrete outcomes: extirpation, no change (e.g., 2000 fish), or return to a healthy population size (e.g., 4000+ fish). For each option, a probability was assigned to each of these three outcomes. This represents the risk profile of the option. The "expected utility" of each risk profile reflects the utility or value of the option under the assumption of risk aversion (Exhibit 2).

For example, if two alternatives have an equal expected value, but one is riskier than the other (has a larger distribution, especially a higher probability of extirpation), its expected utility, adjusted for risk aversion, will be lower (Exhibit 1).

Exhibit 1 Expected Value versus Expected Utility for a Risk Averse Decision Maker

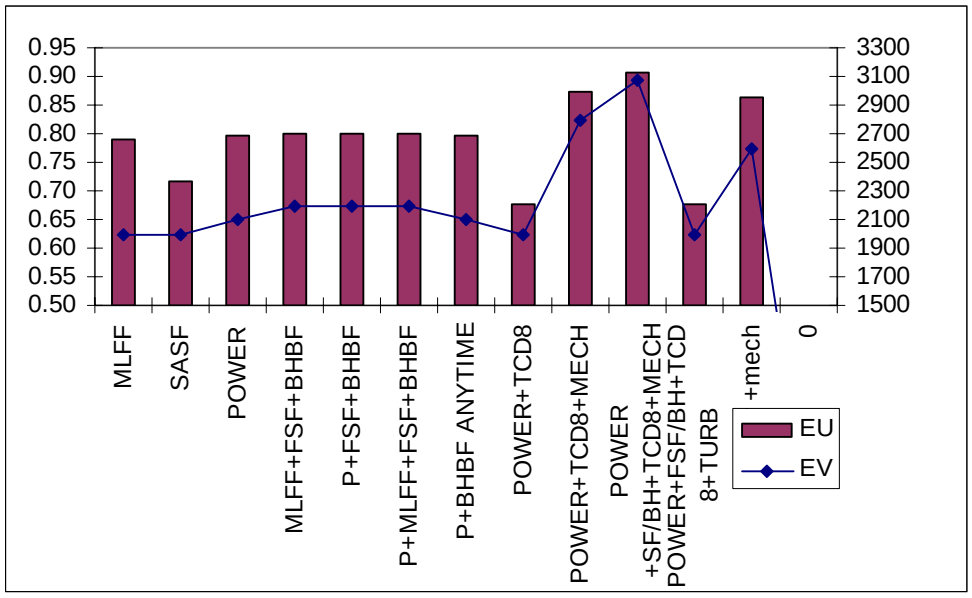
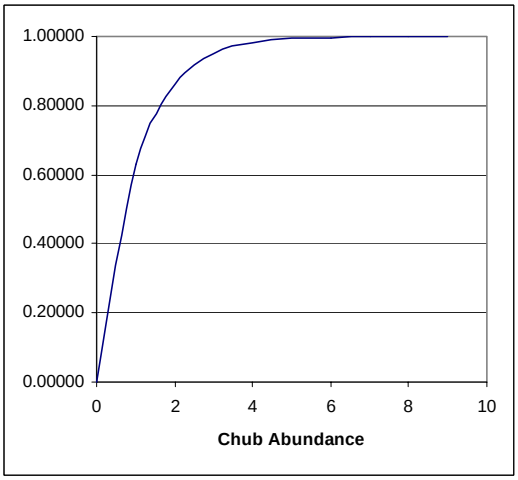


Exhibit 2 Utility Curve for Risk Averse Decision Maker



Appendix C Questionnaires

DIRECT RANKING EXERCISE

INSTRUCTIONS

STEP 1

Rank the Alternatives with 1 being your most preferred alternative. Ties are OK.

STEP 2

A. Assign 100 points to the #1 ranked alternative.

B. Then, assign points to the other Alternatives to reflect their importance relative to the #1 ranked alternative.

EXERCISE

Alternative Name	Rank	Points (from 0 - 100)
MLFF		
SASF		
P		
MLFF + FSF + BHBF		
P + FSF+ BHBF		
P + MLFF+ FSF+ BHBF		
P+ BHBF Anytime		
P + TCD8		
P + TCD8 + MECH		
P+ SF/BH +TCD8 +MECH		
P+ FSF/BH +TCD8 +TURB		
P + MECH		

SWING WEIGHTING EXERCISE

INSTRUCTIONS

For each of the Tables…

A. Rank the attributes in terms of their relative importance, with a rank = 1 being your most important attribute. Ties are okay.

B. Assign 100 points to the #1 ranked attribute.

C. Assign points to the other attribute to reflect their importance relative to the #1 ranked attribute.

Remember to assign points based on how important it is to swing the measure from its worst to its best. If the range from worst to best is very small or very large, that should affect the importance you give it.

NOTE

Start the ranking process and the point allocation anew for each table. (i.e. you should treat each table independently for this exercise). The totals for each table are not relevant, nor are comparisons across tables.

SECTION 1: Low Level Distinction

Table 1

Objective / Location	Performance Measure	Units	Worst Case	Best Case	Rank	Points (0 to 100)
NATIVE FISH - HBC	MS - P establish	%	0%	30%		
	LCR - EU	utility units	0.68	0.91		

Table 2

Objective / Location	Performance Measure	Units	Worst Case	Best Case	Rank	Points (0 to 100)
SPORT FISH - RAINBOW TROUT	Abundance	Abundance; 1 =100,000	0.25	1.30		
	Size	pounds	0.30	1.50		
	Probability of Major Decline	%	20%	10%		

Table 3

Objective / Location	Performance Measure	Units	Worst Case	Best Case	Rank	Points (0 to 100)
CULTURAL	Marshes and SWFC in Marble Canyon (15-20)	0-1 index	0.50	0.80		
	LRZ Vegetated Beach Area	0-1 index	0.40	0.65		
	Historic properties (arch sites)	% of 1984	40%	75%		

Table 4

Objective / Location	Performance Measure	Units	Worst Case	Best Case	Rank	Points (0 to 100)
SAND DEPOSITION	Trend in Storage	slope	-1.00	0.50		
	Total Sand Area above 25kcfs	% of 1984	50%	90%		

Table 5

Objective / Location	Performance Measure	Units	Worst Case	Best Case	Rank	Points (0 to 100)
RECREATION	Probability of Incident	% of trips	25%	5%		
	Campsite Availability	Index; 0.3=current	0.15	0.60		
	LF Trout User Days	Index: 1=20,000 user days	0.80	1.20		
	Powell Boat Access	1=flag	1	0		

Table 6

Objective / Location	Performance Measure	Units	Worst Case	Best Case	Rank	Points (0 to 100)
FINANCIAL IMPACT	Direct power impact	Million $/year; 0=ROD	-$ 85.00	$ 50.00		
	Mitigation $ impact (TCD etc.)	Million $/year	-$ 7.40	$ -		

Table 7

Objective / Location	Performance Measure	Units	Worst Case	Best Case	Rank	Points (from 0 to
WILDLIFE	Peregrine Falcon Abundance (food web)	Index; 1=sev hundred pairs	0.30	0.90		
	Kanab amber snail	Index; 1=1995 level	0.20	0.90		
	Low Riparian Zone Channel Margin Area	Index; 1=1995 level	0.10	0.70		

ECTION 2: High Level Distinction

NOTE: For this section, where there are multiple attributes under a single endpoint consider improving all of these attributes from their worst to best when ranking them as a single unit relative to the other attributes.

Table 9

Objective	Performance Measure	Units	Worst Case	Best Case	Rank	Points (0 to 100)
NATIVE FISH - HBC	MS - P establish	%	0%	30%		
	LCR - EU	utility units	0.68	0.91		
SPORT FISH - RAINBOW TROUT	Abundance	Abundance; 1 =100,000	0.25	1.30		
	Size	pounds	0.30	1.50		
	Probability of Major Decline	%	20%	10%		
CULTURAL	Marshes and SWFC in Marble Canyon (15-20)	0-1 index	0.50	0.80		
	LRZ Vegetated Beach Area	0-1 index	0.40	0.65		
	Historic properties (arch sites)	% of 1984	0.40	0.75		
SAND DEPOSITION	Trend in Storage	slope	-1.00	0.50		
	Total Sand Area above 25kcfs	% of 1984	50%	90%		
RECREATION	Probability of Incident	% of trips	25%	5%		
	Campsite Availability	Index; 0.3=current	0.15	0.60		
	LF Trout User Days	Index: 1=20,000 user days	0.80	1.20		
	Powell Boat Access	1=flag	1	0		
FINANCIAL IMPACT	Direct power impact	Million $/year; 0=ROD	-$ 85.00	$ 50.00		
	Mitigation $ impact (TCD etc.)	Million $/year	-$ 7.40	$ -		
WILDLIFE	Peregrine Falcon Abundance (food web)	Index; 1=sev hundred pairs	0.30	0.90		
	Kanab amber snail	Index; 1=1995 level	0.20	0.90		
	Low Riparian Zone Channel Margin Area	Index; 1=1995 level	0.10	0.70		

Appendix D Two-Option Comparison Tables
Table 1

Moving From Alternative:	P
To Alternative:	P + MECH
Results In:	

	NATIVE FISH - HBC
	No change in MS - P establish of 0 %
	An increase in LCR - EU of 0.06 utility units
	SPORT FISH - RAINBOW TROUT
	No change in Abundance of 0 Abundance; 1 =100,000
	No change in Size of 0 pounds
	No change in Probability of Major Decline of 0 %
	CULTURAL
	No change in Marshes and SWFC in Marble Canyon (15-20) of 0 0-1 index
	No change in LRZ Vegetated Beach Area of 0 0-1 index
	No change in Historic properties (arch sites) of 0 % of 1984
	SAND DEPOSITION
	No change in Trend in Storage of 0 slope
	No change in Total Sand Area above 25kcfs of 0 % of 1984
	RECREATION
	No change in Probability of Incident of 0 % of trips
	No change in Campsite Availability of 0 Index; 0.3=current
	No change in LF Trout User Days of 0 Index: 1=20,000 user days
	No change in Powell Boat Access of 0 1=flag
	FINANCIAL IMPACT
	No change in Direct power impact of 0 Million $/year; 0=ROD
	A decrease in Mitigation $ impact (TCD etc.) of 1 Million $/year
	WILDLIFE
	No change in Peregrine Falcon Abundance (food web) of 0 Index; 1=sev hundred pairs
	No change in Kanab amber snail of 0 Index; 1=1995 level
	No change in Low Riparian Zone Channel Margin Area of 0 Index; 1=1995 level

	Denotes an improvement in the attribute.
	Denotes an worsening in the attribute.
	Denotes no change in the attribute.

Appendix D Continued… Two Option Comparison Tables
Table 2

Moving From Alternative:	**P + TCD8**
To Alternative:	**P + TCD8 + MECH**
Results In:	

	NATIVE FISH - HBC
	An increase in MS - P establish of 0.1 %
	An increase in LCR - EU of 0.19 utility units
	SPORT FISH - RAINBOW TROUT
	No change in Abundance of 0 Abundance; 1 =100,000
	No change in Size of 0 pounds
	No change in Probability of Major Decline of 0 %
	CULTURAL
	No change in Marshes and SWFC in Marble Canyon (15-20) of 0 0-1 index
	No change in LRZ Vegetated Beach Area of 0 0-1 index
	No change in Historic properties (arch sites) of 0 % of 1984
	SAND DEPOSITION
	No change in Trend in Storage of 0 slope
	No change in Total Sand Area above 25kcfs of 0 % of 1984
	RECREATION
	No change in Probability of Incident of 0 % of trips
	No change in Campsite Availability of 0 Index; 0.3=current
	No change in LF Trout User Days of 0 Index: 1=20,000 user days
	No change in Powell Boat Access of 0 1=flag
	FINANCIAL IMPACT
	No change in Direct power impact of 0 Million $/year; 0=ROD
	A decrease in Mitigation $ impact (TCD etc.) of 1 Million $/year
	WILDLIFE
	No change in Peregrine Falcon Abundance (food web) of 0 Index; 1=sev hundred pairs
	No change in Kanab amber snail of 0 Index; 1=1995 level
	No change in Low Riparian Zone Channel Margin Area of 0 Index; 1=1995 level

	Denotes an improvement in the attribute.
	Denotes an worsening in the attribute.
	Denotes no change in the attribute.

Appendix D continued Two-Option Comparison Tables
Table 3

Moving From Alternative:	**MLFF + FSF + BHBF**
To Alternative:	**P + MLFF+ FSF+ BHBF**
Results In:	

	NATIVE FISH - HBC
	No change in MS - P establish of 0 %
	No change in LCR - EU of 0 utility units
	SPORT FISH - RAINBOW TROUT
	A decrease in Abundance of 0.2 Abundance; 1 =100,000
	An increase in Size of 0.1 pounds
	No change in Probability of Major Decline of 0 %
	CULTURAL
	No change in Marshes and SWFC in Marble Canyon (15-20) of 0 0-1 index
	No change in LRZ Vegetated Beach Area of 0 0-1 index
	A decrease in Historic properties (arch sites) of 0 % of 1984
	SAND DEPOSITION
	An increase in Trend in Storage of 0.1 slope
	An increase in Total Sand Area above 25kcfs of 0.1 % of 1984
	RECREATION
	No change in Probability of Incident of 0 % of trips
	A decrease in Campsite Availability of 0.1 Index; 0.3=current
	No change in LF Trout User Days of 0 Index: 1=20,000 user days
	No change in Powell Boat Access of 0 1=flag
	FINANCIAL IMPACT
	An increase in Direct power impact of 16.7 Million $/year; 0=ROD
	No change in Mitigation $ impact (TCD etc.) of 0 Million $/year
	WILDLIFE
	No change in Peregrine Falcon Abundance (food web) of 0 Index; 1=sev hundred pairs
	No change in Kanab amber snail of 0 Index; 1=1995 level
	No change in Low Riparian Zone Channel Margin Area of 0 Index; 1=1995 level

	Denotes an improvement in the attribute.
	Denotes an worsening in the attribute.
	Denotes no change in the attribute.