GCDAMP Knowledge Assessment: Status & Trend

Resource Topic:	Rainbow trout fishery
Preparer(s):	M. Yard, C. Nelson, M. Dodrill, and K. Dibbles, with additions from C. Budwig, J. Jordan, J. Hamill, and J. Miller, plus D. Braun edits
Version Date:	2/17/2017 by GCMRC with additions by angler representatives 3/15/17 and edits by Braun 3/16-19/17

Resource Characteristic	Specific Measure	Status	Trend	Confidence	Rationale: Status/Trend	Rationale: Confidence	Recommendations
LCR Inflow Area & Marble Canyon Rainbow Trout Fishery - Abundance	Multi-state Jolly-Seber open population model implemented in a robust design framework	Moderate Concern	Unknown	Medium	An open population Jolly–Seber model implemented in a robust design framework was used to estimate rainbow trout abundance (Korman et a. 2016). Low trout abundance (N⁓100 RBT; Sep 2016), current state is due to substantial population decline throughout Marble Canyon coupled with low recruitment from upstream sources. Marble Canyon reaches declined by 50% during the period of study (2012-2016), while abundance increased by over 250% in the two reaches above and below the LCR. Trout densities in the LCR inflow area attained a maximum abunadnace level (N ≈ 2,500) by September 2014, and subsequently collapsed to nominal levels. Condition identified as moderate concern because RBT numbers need to be kept low in this area for the BioOP for Chub at the LCR.	Current trend shows numerical stability in population in and around the LCR inflow; however, trout density is likely to show a moderate increase in outlying years due to the 2016 age-0 cohort from Glen Canyon, and other likely recruitment events in the future. Trend in RBT abundance in the LCR inflow is contingent on whether or not local upstream trout populations are repopulated (Korman et al. 2016, Yard et al. 2016, and unpublished data as per Natal Origin Project). Although some reproduction ocurrs in upstream reaches. Recruitment from local reproduction appears insuficient to maintain population size. Also, trend depends on pop at LF which appears to be unpredictable.	Results from across-reach movement model suggests that abundance can be explained by movement from adjacent upstream reaches in Marble Canyon. This points to a need to continue monitoring the recruitment of age0 fish that disperse from Lees Ferry into Marble Canyon during the late-summer and fall at Houserock Reach. Trout identified as moderate concern for Chub at the LCR. As noted previously, anglers not thrilled but believe there has been significant research in this area.
LCR Inflow Area & Marble Canyon Rainbow Trout Fishery - Age distribution	Length at age and trends in mean age and birth year	Good Condition	Unchanging	Medium	Metric: Length-at-age curves based on von Bertalanffy parameter estimates. Asymptotic length (mean length if they were to grow for an infinitely long period) ranged from 299 to 348 mm (11.75" - 13.7") across all reaches.	Mean age of rainbow trout increased over the duration of the study in Lees Ferry and Houserock reaches. For example, in reach I, mean age on the April 2012 trip was 1.2 years and increased to 3.4 years by the September 2014 trip. This occurred because a very large annual cohort was produced in 2011 and there was limited recruitment in later years, so the mean age of the population increased as the dominant 2011 cohort aged.	Based on the current range of asymptotic lengths, most fish in Lees Ferry are not going to attain a length that meets AGFD Angler Catch Quality (10 fish ≥14" /day)

LCR Inflow Area & Marble Canyon Rainbow Trout Fishery - Growth	Growth rates for length and weight	Moderate Concern	Unknown	Medium	Length based and weight based method based on PIT-tag recaptures (Yard et al. 2016). In 2016, growth was elevated in spring and summer, similar to Lees Ferry. Growth results suggest that the two RBT river sections function partially independent of each other. Growth in the upper section (Glen Canyon) may largely be controlled by strong density-dependent top-down effects, while growth in the downstream section (Marble Canyon and LCR inflow area) is more likely regulated by densityindependent factors such as turbidity. there were strong annual-, seasonal-, and reach-specific differences in growth in length and weight.	Seasonal and spatial trends in invertebrate drift concentration likely drove some of the patterns in trout growth and condition. Growth-in-length showed stronger temporal rather than spatial variation in growth, which was likely caused by a seasonal variation in food availability, prey detection as determined by turbidity, and energy expenditure. In winter (January–April) there was modest growth in length and substantial growth in weight in downstream reaches where food availability at this time was higher. In later months, trout growth was highest in spring (April–July) in all reaches, when water is generally clear even in the most downstream reaches where trout densities were lower. Trout in the downstream reaches did not grow in length over the summer and lost weight when turbidity was high owing to inputs from Paria River and LCR, which likely reduced foraging efficiency. Growth in fall (September–January) was poor in all reaches when food availability was low.	
LCR Inflow Area & Marble Canyon Rainbow Trout Fishery - Movement	PIT-tag initial capture versus recapture site difference	Moderate Concern	Unknown	Medium	PIT-tag recapture data (N = 16,379), assessment of movement based on differences between spatially referenced sites for initial capture and recapture. There is a low probability for an individual fish to move large distances. Less than 1% of recaptures making movements greater than 20 km. because of high trout densities in upstream source areas, this small dispersal rate was sufficient to explain the threefold increase in the relatively small population near the LCR (Korman et al. 2016). Condition identified as moderate concern because RBT numbers need to be kept low in this area for the BioOP for Chub at the LCR. Fish at LCR are migrating from LF.	Reducing dispersal rates of trout from upstream sources is the most feasible solution to maintain low densities near the LCR to minimize negative effects of competition and predation on humpback chub. Age0 fish appear to disperse downstream into the upper sections of Marble Canyon; these dispersal events (2011 & 2016) are not always in proportion to the quantity of recruits produced in Lees Ferry. Fish at LCR are migrating from LF. Confidence rates medium because the status is dependent on the pop at LF. For the last five years one could argue that the concern was low, and prior to that it was high.	

LCR Inflow Area & Marble Canyon Rainbow Trout Fishery - Piscivorous activity	Incidence of fish remains in stomach contents	Moderate Concern	Unchanging	Medium	Metric: Incidence of piscivory based on diet analysis (Yard et al. 2011). The incidence of piscivory for rainbow trout (0.5–3.3%) was much lower than that for brown trout. However, rainbow trout were almost 50 times more abundant than brown trout, and thus our estimates suggest that rainbow trout predation accounted for more than half of the total number of fish consumed in the study area. Although rainbow trout were less piscivorous than brown trout, their greater abundance resulted in a cumulative piscivory effect that was much greater, representing 65% of the total fish consumed during the study period (2003–2004).	Even though rainbow trout had a large cumulative piscivory effect, the annual per capita consumption rate was low overall; on average, each rainbow trout consumed 4 fish/year in the upstream reach and 10 fish/year in the downstream reach. Incidence of predation by rainbow trout increased with increasing native fish prey availability and sediment concentration. At the onset of turbid conditions may cause rainbow trout to move from territorial feeding lanes into the shallow shorelines occupied by native fishes and to switch from drift feeding to other foraging strategies that involve more active hunting or opportunistic predation.	The use of turbidity as a predator control mechanism will probably have different transient and long-term effects on rainbow trout than on brown trout. Anglers suggest that study is complete - not thrilled with the results but feel this subject has been answered.
LCR Inflow Area & Marble Canyon Rainbow Trout Fishery - Recruitment	Modeled estimates based on Jolly-Seber model and estimates of emigrants based on across-reach movement model	Good Condition	Unchanging	Medium	Metrics are modeled estimates of recruitment based on Jolly-Seber model and estimates of emigrants based on across-reach movement model (refer to Korman et al. 2016). In 2016, there was minimal indication of recruitment in the LCR inflow area through either local reproduction or dispersal from upstream sources. This has resulted in the continuation of low abundance levels in the LCR inflow area. Recruitment estimates (reproduced locally + immigrants) based on the Jolly Seber model were found to be equivalent to estimates based on a movement model using Cauchy distributions to estimate the quanity of emigrants across all reaches and trip intervals (Korman et al. 2016). Results strongly suggest that recruitment in the LCR inflow area is primarily from trout movement and not reproduction. Good Condition because local recruitment in these reaches is not desired and it appears to be unchanging.		Continue to monitor dynamics in annual recruitment among Lees Ferry, upper Marble Canyon, and the LCR inflow area. As a metric, focus on the changes in the length frequency distributions of age0 fish during late summer and fall, particularly since larger fish demonstrate limited downstream movement.
LCR Inflow Area & Marble Canyon Rainbow Trout Fishery - Survival	90-day apparent survival rate based on the null model	Moderate Concern	Unknown	Medium	Metric is the 90-day survival estimates derived from the Jolly-Seber Models. Between 2012 and 2014, 90 day survival rates in all upstream reaches averaged 0.81 compared with 0.59 in the LCR inflow area. (This average 90-day surival rates would be equivalent to an anverage annual survival rate of 0.12)	The survival trends explain the reduction in the population sizes in the Marble Canyon reaches.	

Lees Ferry Rainbow Trout Sport Fishery - Abundance	Multi-state Jolly-Seber open population model implemented in a robust design framework	Significant Concern	Unknown	Medium	Low trout total abundance (N ≈ 150 K; Oct 2016; Lees Ferry Model). Analysis based on multi-state Jolly-Seber open population model implemented in a robust design framework. Manuscript in review entitled "Trends in recruitment, abundance, survival, and growth over a boom-and-bust cycle of a Rainbow Trout tailwater population." Current state due to population decline brought about by changes in survival coupled with low recruitment of age0 trout across years from 2013 to 2015. Current population trend shows numerical stability in population; however, trout density is likely to show a moderate increase due to recruitment from the 2016 cohort. So recruitment looked good last two years but not enough years of evidence to say if positive yet.	Abundance levels are governed by intrinsic population factors (growth, survival, and reproduction) and availability of benthic preybase. High certainty about estimates for population abundance levels. Uncertain about trend - 2016 showed positive trend but too soon to know if this is evidence of recovery - particularly if abundance levels should increase without similar increases in the aquatic foodbase, or without complimentary decreases in trout growth and condition to offset increases in density. Sizeable numbers of 2016 Age0 cohort recruited into population. Combination of factors: Higher than average number of annul recruits and higher survival rates currently suggest that population should start to increase in outlying years, but since this is not definite, confidence=Medium.	Continue to monitor trout population demographics.
Lees Ferry Rainbow Trout Sport Fishery - Abundance	Size- & spatially- stratified open population model (Korman and Yard, Manuscript in review)	Significant Concern	Unchanging	Medium	Trout abundance (N ≈ 1.15 M; Apr 2012), past changes in abundance over the last 5 yrs. suggests that the Lees Ferry population declined across years (>85% reduction in population) since preceding good conditions. However, the shorter-term decline may be part of larger pattern of "boom and bust," so not clear if there is a long-term trend or not. Estimates derived from size- & spatially- stratified open population model (Korman and Yard, Manuscript in review). Inter-annual variation in survival rates had a very large effect on the estimated abundance trend. The population decline we observed was certainly determined in part by temporal variation in recruitment, as annual recruitments between 2012 and 2016 were on average 10-fold lower than the large recruitment event in 2011 that occurred just prior to the start of the study.	Based on current abundance and past evaluation of CPUE trends indicates that this trout population exhibits boom-bust cycle at a frequency of 10-12 yrs. A number of factors (high flow experiments and reservoir nutrient dynamics) are hypothesized to be the underlying cause. There seems to be no reason to suspect boom/bust is stopping. Medium confidence based on consistent data but uncertainty about whether trend is declining or is part of longer-term "boom and bust" pattern.	Research is needed to determine what is the major factor determining variation in aquatic preybase. As a response variable, trout need to be monitored for effects from high flow experiments and reservoir nutrient dynamics.

Lees Ferry Rainbow Trout Sport Fishery - Age0 abundance	RTELSS Age0 abundance (Avery et al. 2015)	Significant Concern	Unknown	Medium	Significant concern because variability does not lend itself to a stable fishery. The July 2011 population estimate was 686,000 for Age0 RBT (95% CI: 563,000–864,000), the second highest on record for all study years, following only the 2008 estimate of 883,000 fish (95% CI: 647,000–1,168,000). The range of July population estimates for all years was 93,000–883,000 fish (difference of 790,000). The November 2011 population estimate was 214,000 fish (95% CI: 175,000–253,000), the highest on record for all study years and more than two times the next highest estimate (100,000 fish in 2012). The range of November population estimates for all years was 16,000–100,000 fish (difference of 84,000, 2011 excluded).	Variability also makes it difficult to tell if there is a trend, and reduced confidence in assessment of status.	
Lees Ferry Rainbow Trout Sport Fishery - Age0 Survival	Fall abundance of surviving recruits for Age0	Moderate Concern	Unknown	Medium	Fall abundance estimate of surviving recruits for Age0 (75-124 mm FL) is N = 76 K. Estimates are derived from the Lees Ferry model (multi-state Jolly-Seber open population model implemented in a robust design framework, in review Korman et al.). This fall October 2016 estimate is similar to estimates made for 2012 (N = 77 K). Abundance of these fall recruits contrasts sharply with past estimates made over the last three years (fall abundance of Age0 fish is 3.5 fold greater than estimates made between 2013 and 2015).		Annual recruitment of Age0 trout is a critical information for determining the likely trends in population growth. Need to reconcile the differences in recruitment found between RTELLS catch indices and mark-recapture estimates. Suggest re-estimating RTELLS capture probabilities since these have not been revised since 2007.
Lees Ferry Rainbow Trout Sport Fishery - Condition	Relative condition factor	Good Condition	Unknown	Medium	Relative condition factor is the ratio of observed weight to predicted weight for each fish and then averaged for each reach and trip. Elevated condition factor across spring and fall for all size-classes. Average condition factors are higher in 2016 than all previous years (2012-2016). In 2016, condition factor (1.18) was elevated for larger sized (catchable size) trout (≥275 mm FL)		Higher growth and condition of trout in reaches with lower trout densities suggests that reducing trout abundance in Glen Canyon could increase the size of trout in the tailwater fishery
Lees Ferry Rainbow Trout Sport Fishery - Growth	Growth rates for length and weight	Good Condition	Unknown	Medium	Growth rates for length and weight in 2015 and 2016 are elevated. There was substantial variation in growth rates among seasons and years. Within a year, growth was always highest between April-July and July-September intervals, and was greatest during these intervals in 2012 and lowest in 2014. Trout growth in Glen Canyon was generally lower than that in downstream reaches. Unlike downstream reaches it is likely that the very high trout densities in Glen Canyon excceded the consumptive demand relative to prey avilability, which resulted in reduced growth.	Growth was low during fall and winter periods in 2011 through 2013 but was higher during these season beginning in winter of 2015. Relative condition factor also showed inter-annual and seasonal trends as determined largely by changes in growth in weight (Yard et al. 2016; Korman and Yard in review)	Higher growth and condition of trout in reaches with lower trout densities suggests that reducing trout abundance in Glen Canyon could increase the size of trout in the tailwater fishery. Reduced growth of trout in the Glen Canyon population affected multiple life history stages and processes, all potentially causing negative feedbacks that would regulate abundance and biomass.

Lees Ferry Rainbow Trout Sport Fishery - Movement	Movement	Good Condition	Unchanging	High	Metric consists of length-based and weight-based method based on PIT-tag recaptures, across-reach movement model, and length-frequency distributions. Trout > 75 mm (fork length) demonstrate limited movement based on differences between release and recapture locations. 95% of recaps moved no more than -2.7 km upstream and 2.9 km downstream (movement based on PIT-tag recaptures [N>16,000]; Korman et al. 2016, and analysis updated with other unpublished data as per Natal Origin project). Results based on the recapture of PIT-taggable sized fish (> 75 mm FL) also suggest that the movement of individual fish from Lees Ferry downstream is episodic (2014). For the most part, very few of the long-distance movers (> 75 mm FL) that disperse to the LCR inflow region originated from Lees Ferry. The contribution of fish from Lees Ferry appear to be in the smaller size classes of age0 fish that move into the upper sections of Marble Canyon between July and September. The movement appears infrequent and is associated with two cohorts (2011 and 2016).	Long-distance movement data suggest that dispersal of rainbow trout increases following periods of high recruitment (2011 & 2016) and also when condition factor is low, which has been observed in other systems (Korman et al. 2016). The presence of age-0 trout and their recruitment to larger size classes as seen from length–frequency distributions provides evidence for local recruitment in reaches downstream of Glen Canyon. A comparison of length–frequencies across reaches and trips indicated that most age-0 fish are produced in Lees Ferry and very few small rainbow trout are found downstream of Glen Canyon. Length–frequency distributions revealed the presence of a dominant cohort produced in 2011 in Glen Canyon, which determined the trajectory of abundance and the likely source of most immigrants to the LCR over the study period. In 2016, a similar cohort of age-0 moved from Lees Ferry to repopulate upper Marble Canyon. The window of time for Age-0 fish (median size-class 60-69 mm FL) movement ocurred between July and September.	(1) One could argue that any movement is bad from the standpoint of the recreational fishery. Given the evidence of movement - sufficiently studied to be assumed a fact - studies are now needed on the factors affecting movement. For example if "bug flows" improve food base it would be good to know if that alters downstream movement rates. (2) The underlying assumption of the movement models used in the LTEMP-EIS process is that the number of migrants moving into Marble Canyon is proportional to number of recruits in Glen Canyon. If substantive Age-0 movement occurs when recruitment events in Glen Canyon are small then management actions are not likely to limit trout population increases in Marble Canyon. Therefore, we suggest monitoring the movement of age-0 trout into Marble Canyon to assess future increases in trout abundance due to recruimtent in Marble Canyon, as well as efficacy of Trout Management Flows to reduce recruitment events in Lees Ferry.
Lees Ferry Rainbow Trout Sport Fishery - Recruitment	Annual recruitment	Significant Concern	Unknown	Medium	Annual recruitment analysis estimates that 1.1 million recruits were produced in 2011, based on the estimated survival rate for the smallest size class between the November 2011-April 2012 interval (90-day survival of 0.60). This was more than 10-fold greater than the average of recruitment estimates between 2012 and 2016. The average annual recruitment varied by as much as 7-fold across years. Recruitment was greatest in 2012 and lowest in 2014	Lower rate of sexual maturation for both females and males in 2015 was likely driven by very poor condition in fall 2014 and winter 2015. This resulted in reduced recruitment in subsequent years. Recruitment is strongly linked to flow and growth (Korman et al. 2012; Yard et al. 2016; Korman and Yard in review)	
Lees Ferry Rainbow Trout Sport Fishery - RTELSS Age0 recruitment	RTELSS Age0 abundance (Avery et al. 2015)	Moderate Concern	Unchanging	Medium	RTELSS Age0 abundance (Avery et al. 2015) is monitored by electrofishing low-angle and high-angle near-shore habitat. Status of 2016 November population estimates of Age 0 Rainbow Trout derived from ongoing Early Life Stage monitoring indicate recruitment of age 0 trout has remained relatively stable over past four years.	Uncertainty exists due to differences between RTELSS and NO recruitment estimates for Age0 trout. Confidence in these measures are directly related to the consistency of the resource in terms of food and habitat availability, flows, and the potential for negative Brown Trout interactions.	Need to reconcile why these differences exist by conducting additional mark-recapture to determine if capture probabilities are variable for these early life history stages.

Lees Ferry Rainbow Trout Sport Fishery - Spawning magnitude/hatch success	RTELSS Redd counts (Korman et al. 2011; Avery et al. 2015)	Moderate Concern	Unchanging	Medium	RTELSS Redd counts (Korman et al. 2011; Avery et al. 2015) indicate spawning magnitude/hatch success. Status of total and estimated Redd counts have remained stable over past several years, translating into relatively consitent recuruitment of age 0 trout. Trend would likely continue under similar flow regimes. In 2011, a year defined by high, steady flows, Rainbow Trout redd deposition estimates were almost double the average observed since monitoring began in 2004 (Avery et al. 2015).	Based on the distribution of redd counts through time, spawning extends from late-November to late June, with peak spawn in late-March early April. However, there is a limited relationship between total Redd deposition and recruitment due to factors like superimposition, suggesting that number of Redds not directly indicative of recruitment. Several factors linked directly through flows influence both spawn magnitude and incubation success, so confidence in these measures are directly related to flow regimes (Korman et al. 2011).	Discontinue Redd counts and place greater emphasis on sampling and estimating abundance and survival of Age0 recruits.
Lees Ferry Rainbow Trout Sport Fishery - Survival	90-day apparent survival rate based on the null model	Significant Concern	Unchanging	Medium	Metric is the 90-day apparent survival rate based on the null model, where survival was held constant across all size classes and trip intervals. Current rate is estimated as 0.84, equivalent to an annual rate of 0.50 (S90^365/90). Estimates derived from size- & spatially-stratified open population model (Korman and Yard, Manuscript in review). Our estimate of the annual survival rate over the study period is lower than what would be expected given the average growth coefficient for this population, but is slightly better than what would be expected given the average survival of trout in other systems. Survival rates of age0 fish are variable among years and likely due to density dependent and growth dependent factors. Survival rates for adult fish are typically high and constant; however, anticedent conditions that effect . Note that the reference range for survival rates are not specified clearly in management policy or guidance. Estimates derived from size- & spatially- stratified open population model (Korman and Yard, Manuscript in review). Survival was much lower during the fall in all years for the smallest size class (75-124 mm FL). Lower survival for the larger size classes (≥ 275 mm FL) was most common during fall and winter periods.	Survival rate varied among size classes, indicating strong support for size-dependent variation in survival rate, with increasing survival over the 1st four size classes, and a modest reduction in survival for the largest size class. 90-day survival rates for the three largest size classes in 2014, 2015, and 2016 were 11, 21, and 22% lower than the average from 2012 and 2013, respectively. All survival models tested, estimated that the rainbow trout population in Glen Canyon declined from about 1,000,000 to 150,000 fish over four years between April 2012 and July 2016 and then a small recovery at the end of the study period.	Important parameter when assessing the effect of causal factors in an experimental framework

Rainbow Trout Maximum size	Maximum predicted mass (g) of an average individual in the population based on bioenergetic model (Dodrill et al. 2016)	Significant Concern	Unknown	Low	Metric - Maximum predicted mass (g) of an average individual in the population based on bioenergetic model (Dodrill et al. 2016). Depending on the time frame considered, rainbow trout maximum size could be viewed as deteriorating (i.e., from the 1980's to today) or unchanging (i.e., since mid 2000s to today).	Drift-foraging bioenergetics model approches have been used to predict maximum size of an average individual in the population in relation to both biological conditions (i.e., invertebrate drift) and physical factors (i.e., water temperatures). This work in combination with empirical estimates of rainbow trout maximum size document the status and trends through time.	1). Continue monitoring the resource characteristic by field sampling efforts designed to estimate maximum size. 2). Apply modelling tools (such as drift-foraging bioenergetics or Net Energy Intake models) to predict how changing biological or physical conditions influence the maximum size that rainbow trout can attain. 3). Use both empirical studies and modeling approches to build an explicit understanding of how management actions influence the resource. 4). Consider whether to reduce or simplify study, given angler perceptions that bioenergetic model results are already solid.