PEER REVIEW OF THE RECOMMENDED MINIMUM FLOW FOR THE RAINBOW RIVER SYSTEM

Final Panel Review Document

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Panel

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EXECUTIVE SUMMARY

The Peer Review Panel's (Panel) evaluation of the data, assumptions, and methodologies used by the Southwest Florida Water Management District (District) to assign a recommended minimum flow for the Rainbow River System ("Recommended Minimum Flow for the Rainbow River System Peer Review DRAFT," SWFWMD 2016) is summarized in this document. The Panel consists of Matt Cohen, Ph.D., Lee Wilson, Ph.D., and Dann Yobbi, P.G. The District provided the Panel with a specific set of *charges* defining what should consider during the review. During the review process, open discussions regarding the data, analyses, and report conclusions were held among District staff, Stakeholders, and Panel members.

The District's report successfully meets the requirements of the statute--to consider multiple *natural resource values (WRVs)*, and limit flow reduction resulting in no *"significant harm"* to water resources and ecology of the system. Overall the analyses were thorough, scientifically reasonable, and based on the best available data. Data used in analyses were collected properly and reasonable quality control assessments were performed. The approach used to select the minimum flow threshold for the Rainbow River System followed established methodologies used previously by the District.

Recurrently "*significant harm"* is set at 15% in MFL proposals; however, the suitability (or correctness) for protecting the resource and environment is unproven and needs defensible confirmation and validation. Furthermore, the report does not discuss other, possibly more stringent standards of "*significant harm"*. The Panel considers the adoption of a 15% threshold in the reduction of habitat availability from current or baseline conditions is presumptive and unverified based on the data presented in the Rainbow River System report. We concur with the Weeki Wachee River System Peer Review Panel's report, that "*one size probably does not fit all and that some ecosystems may well tolerate reductions greater than 15% while others may tolerate considerable less, especially if they are already stressed by physical, chemical, or biological factors other than streamflow*" (Powell and others, 2008). The Rainbow River System has state and federal recognition, designated as both an Outstanding Florida Water and a National Natural Landmark due to its exceptional ecological and aesthetic characteristic. However, the system is threatened, added to the FDEP verified list of impaired waters in 2010 due to its high nitrate levels and excessive algae growth (algae mats) in 2013. The National and State recognition alone may be justification for the District to consider a more stringent threshold standard when determining *"significant harm"*. The Panel recommends that additional discussion and guidance be provided by the District with regard to how the District interprets the threshold of "*significant harm*" when assigning a minimum flow on an Outstanding Florida Waterway and a National Natural Landmark. As with previous Panels, we urge the District to reduce the uncertainty and subjectivity associated with threshold selection or at least be transparent as to the degree of uncertainty.

Multiple habitats were capped at a 15% threshold (allowable habitat reduction) for an associated spring discharge. The most vulnerable was *inundation duration of floodplain wetland habitat* with a 15% reduction in size at a corresponding 5% decrease in discharge. Other habitats, for example *fish passage and instream woody habitat,* the threshold of 15% was reached when discharge decreased by 9%. Therefore, the District averaged the most vulnerable (conservative) and less vulnerable habitat change thresholds and associated decreased flows of 5% and 9% for a recommended 7% permissible flow reduction for all aspects of the Rainbow River System. The report does not provide clear and defensible justification for the selection of 7% giving the impression that the selection was arbitrary rather than founded in scientific analysis. The Panel agrees that District staff have provided a more thorough discussion of the rationale to support the 7% flow reduction but feel that defensible evidence should be included in the report. While the Panel is compelled by the District's argument that the stage decline associated with 5% vs 7% flow reduction is extremely small and well within the range of tolerance of wetland fauna and flora in other settings, the case of whether the effects of lowered stage in lakes with fringed cypress wetlands are analogous to stage decline effects in Rainbow River requires explicit description in the document. Although the subsequent technical memorandum addresses the 7% rationale, the District should proceed with a more conservative approach focusing on the most conservative flow reduction value especially since there was no analysis of uncertainty associated with modeling efforts or the confidence level at which any analysis associated with "*significant harm*" was being applied. A thorough discussion of sources of uncertainty and how uncertainty was controlled or dealt with would be helpful additions to the report and would aid in interpreting the results.

The Panel noted conflicting results reported in appendix B. Results are from a frequency analysis to determine minimum flows on the Rainbow River conducted by HSW Engineering, Inc (2009). A frequency analysis approach has successfully been used by SJRWMD to defensibly implement MFLs on priority rivers in their jurisdiction. Results of the frequency analysis show that the District's recommended allowable flow reduction of 7% for the Rainbow River System is not protective of most of the *WRVs*. Furthermore, the frequency analysis approach reinforces flow reduction protection up to 5%, but not often above that. A thorough discussion of the differing results from the two approaches is suggested to address this concern.

The Panel finds the 2000 flow anomaly a potentially interesting harbinger of change. The springshed is clearly yielding less flow than expected since 2000. Based on the double mass analysis it appears that current flows are substantially below the MFL and there is nothing in the report that assures recovery to the MFL. The Panel understands that the cause is unknown, while groundwater models suggest that local pumping is not the cause, the Panel has major concerns that the flow anomaly must be considered a "departure from natural flow". Resolving the origin of the anomaly is critical to defensibly conclude that the Rainbow River System is, in fact, not impaired and in need of a recovery plan. The Panel appreciates that MFL reports are living documents, updates and improvements should clearly describe knowledge gaps, and that remedying these gaps are a District priority.

The Panel found the water quality discussion to be overly simplistic. The Panel recommends additional analyses to ensure that the proposed MFL does not result in relevant water-quality standard exceedances or enhance algal growth (mats). Due to existing impairment (excess nutrients) and the river's designation as an Outstanding Florida Waterway and a National Natural Landmark, it seems prudent to confirm that any water withdrawals will not negatively affect the water quality of the river. Typically, MFLs do not consider factors such as a TMDL. However, for this system, nutrient loading is relevant when assigning the MFL in that it can lead to vegetation changes (increased SAV) which in turn lead to hydrologic changes (reduced flow relative to aquifer head). It appears that the District has not yet resolved all the causal relations of interest to explain the change in flows, but nitrate concentrations are a candidate factor. The Panel is sympathetic to the relative absence of data for these sorts of determinations, but it's only by documenting these knowledge gaps formally in reviews like this that future knowledge acquisition efforts are motivated. In the absence of key supporting data, the District should consider capping withdrawals at current levels (or with a minimal allowable increase) until the nutrient issues are effectively addressed. In particular, consideration should be given to allow no reduction in flow unless there is a corresponding decrease in loading so that there is no net increase in projected nitrate concentrations. If this cannot be done, the District needs to be explicit as to the water-quality implications of the proposed MFL. Underlying this recommendation is our perception that the system, while still in relatively good shape, is substantially overused to the point that any reduction in flow could impact water quality and should be of concern.

While our overall assessment of the Districts effort is supportive, there are some key knowledge gaps that the report revealed that should be addressed and prioritized for future efforts. The Panel makes the following recommendations:

1. The Rainbow River and Silver Springs Systems are hydrologically connected and therefore the Panel recommends future revisions of the MFL standards be considered conjointly. It was expressed by District staff that this coordination in ongoing and vigorous, and for that the Panel applaud both districts. However, it's still not clear to the Panel whether this includes a joint determination of changing flows to regional pumping impacts.
2. The effects of backwater on Rainbow River flows during high flow conditions on the Withlacoochee River and resulting rating-curve development issues should be investigated. Additionally, the flow anomaly since 2000, indicated on the double mass plot, needs to be explained. The origin of this anomaly either by vegetation drag (as proposed in Silver Springs), downstream head-boundary conditions, or other unknown

factors is critical for setting MFLs and definitively able to conclude that the river is, in fact, not in need of a recovery plan.

3. A number of water-quality issues were not addressed and warrant explicit mention in the report, even if the finding is that sufficient data do not yet exist to establish the link for this system. These include:
   - *Integration of coves (and chlorophyll-a) into the MFL*— A unique feature of the Rainbow River system are old phosphate pits that adjoin the river, and, in some cases receive river water inputs. These coves are potentially important aquatic systems in their own right, and have been shown vulnerable to significant phytoplankton accumulation. A decline in river discharge will lengthen the resident time in the coves, and this, will enhance chlorophyll-a concentration in the water returning to the river. Insofar as this is a degradation of water quality, it seems to warrant further investigation.
   - *Algal accumulation*--One major ecological change observed in Rainbow River, particularly in the lower reaches, is the accumulation of filamentous algal mats, and the commensurate decline in submerged aquatic vegetation (as well as increased dominance of Hydrilla verticillata, an invasive exotic). While the provenance of these ecological changes is not entirely clear, and likely a response to several overlapping stressors, one emerging theme in the springs literature is that flow velocity plays a significant role in algal cover. Where velocities are high, algal cover tends to be low, and while algal cover can vary dramatically at low velocity, proliferation of mats that smother SAV is clearly possible. It was therefore surprising to see consideration of this algal proliferation issue not mentioned. Given that the link with discharge is direct, it warrants explicit mention in the report.
   - *TMDL on the Withlacoochee River*-- Another peculiar feature of the Rainbow River is that the sediments transition longitudinally from coarse sands in the upper river to dense phosphatic clays in the lower river, a legacy of active phosphate mining that occurred in the area between the 1880's and 1930's. As a result of the change in texture and the change in mineral composition, the sediments in the lower river are a massive source of P to the river, increasing the P concentration from roughly 20 $\mu g\ L^{-1}$ at the head spring to over 150 $\mu g\ P\ L^{-1}$ by the confluence with the Withlacoochee River. There is no numeric nutrient standard for P for springs or spring rivers, but the existence of TMDLs for downstream waters makes this rise in concentration a significant potential impact. Nutrient loading is relevant to the MFL in that it can lead to vegetation changes which in turn leads to hydrologic changes.
   - *Dissolved Oxygen*--One key correlation in springs across the state is between flow and dissolved oxygen, with potentially important ecological impacts via effects on invertebrate algal grazers as well as mobilization of redox sensitive solutes like iron. We note, however, that Rainbow River has consistently among the highest DO levels of any of the major springs, so that correlation may be less significant. Nevertheless, given the link with discharge, it warrants further investigation.

INTRODUCTION

The Southwest Florida Water Management District (District) under Florida law (Chapter 373.042) has been directed to establish minimum flows and levels (MFLs) of priority water bodies within its jurisdiction. MFLs are the minimum flows and/or water levels adopted by the District Governing Board as necessary to prevent "*significant harm*" to the water resources or ecology of the area resulting from water withdrawals. *Minimum flows* are defined by Florida Statutes (Chapter 373.0421) as "the minimum flow for a given watercourse shall be the limit at which further withdrawal would be significantly harmful to the water resources of the area." A *minimum level* is defined as "the level in an aquifer and the level of surface water at which further withdrawal would be significantly harmful to the water resources of the area." Regrettably, the statue does not define "*significant harm*." Statutes provide that MFLs shall be calculated using the "best available information".

Florida law contains additional guidance when determining the recommended MFL for the water body. Chapter 62-40.473 FAC lists 10 "environmental values" (referred to "water resource values" or WRVs) to be addressed:

1. *Recreation in and on the water;*
2. *Fish and wildlife habitats and the passage of fish;*
3. *Estuarine resources;*
4. *Transfer of detrital material;*
5. *Maintenance of freshwater storage and supply;*
6. *Aesthetic and scenic attributes;*
7. *Filtration and absorption of nutrients and other pollutants;*
8. *Sediment loads;*
9. *Water quality; and*
10. *Navigation.*

The District, under Florida statutes provides peer review of methodologies and studies that address the management of water resources within their jurisdiction. The development of a recommended minimum flow for the Rainbow River System used analyses similarly performed on a number of rivers and springs including the: Anclote, Alafia, Upper Braden, Chassahowitzka, Gum Slough, Hillsborough, Homosassa, Myakka, Peace, Sulfur Springs, Upper and Middle Withlacoochee, and Weeki Wachee--all were peer reviewed. The Rainbow River System MFL methodologies incorporate many of the recommendations from these peer reviews, as well as improvements developed by District staff. In August 2016, the District retained 3 scientists to peer-review the report and associated study documents *"Recommended Minimum Flow for the Rainbow River System, Peer Review DRAFT"*, *by Kym Rouse Holzwart, Yonas Ghile, Ron Basso, Stacey Day, and Doug Leeper*. The 104-page report includes 9 chapters describing the data, methodology, and analyses used to determine the recommended minimum flows. Supporting documents consist of an additional four appendices with approximately 400 pages.

The scopes of services consisted of the following general review charges:

1. *Complete a "conflict of interest" form.*
2. *Review a draft report on the proposed minimum flow for the Rainbow River System, and review, as appropriate, other material related to the concepts and data presented in the draft report.*
3. *Participate in multiple publicly noticed events, including a meeting held at a location within the District, a field trip to sites on the Rainbow River system, and teleconferences facilitated by the District to support peer-review discussions and work efforts.*
4. *Collaborate with the other peer review Panelist to develop a final peer document that: summarizes findings of the peer review Panel; identifies, as appropriate, areas of agreement and disagreement among Panelists; and includes suggestions, if any, for additional data collection or analyses may be incorporated into the process of establishing the minimum flow for the Rainbow River System.*
5. *Provide follow-up services where needed.*

After a reconnaissance survey of the Rainbow River System on September 20, 2016, the Panel held an initial meeting facilitated by District staff, discussed issues and analyses regarding the draft report with District personnel, the scope of the review, and subsequently prepared independent scientific reviews of the Districts August 2016 draft report and supporting appendices. One teleconference call and electronic correspondence among Panel members and District staff were conducted to update progress of review, and discuss issues (technical concerns) regarding the draft MFL report. The Panelist's reviews were compiled by the Panel chair and edited by all members resulting in the document presented herein. This document was generated by electronic correspondence via a web board established and maintained by District staff. District staff is to be commended for their response to questions and data requests from the Panel members after our initial reading of the District's draft report. District staff did an excellent job of conducting open discussions with the Panel regarding the analyses in the MFL draft report.

The District considered the following 4 elements to be the most relevant *Water Resource Values* (*WRVs*) influencing the selection of recommended MFL for the Rainbow River System. A "weight of evidence" approach was applied.

1. *Establishment of a low-flow threshold based on flows for fish passage and maintenance of water depths above lowest wetted perimeter inflection point (e.g., maintaining the maximum amount of instream habitat quantity with the lowest rate of flow). This criterion is associated with recreation in and on the water, the maintenance of fish passage, fish and wildlife habitats, and navigation.*

2. *Protection of instream habitat for selected functional and taxonomic groups of fish and benthic macroinvertebrates. This criterion is associated with fish and wildlife habitats, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, and sediment loads.*

3. *Inundation of instream woody habitats, including snags and exposed roots, in the stream channel. This criterion is associated with recreation in and on the water, fish and wildlife habitats, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, and sediment loads.*

4. *Maintenance of seasonal hydrologic connections between the river channel and floodplain wetlands to ensure availability of inundated wetlands habitat and persistence of floodplain structure and function. This criterion is associated with recreation in and on the water, fish and wildlife habitats and the passage of fish, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, sediment loads, and water quality.*

Field data and numerical modeling approaches were used to address the *WRVs* and quantify the minimum flow recommendation for the Rainbow River System. The methods used to quantify the *WRVs* listed above are described in the following sections. This review document parallels the structure of the Districts draft report and reflects the collective input of the Panel. Additional editorial comments are provided at the end of the review.

RESULTS OF THE PEER REVIEW

The Districts draft technical report presents the available information and analyses for support of the recommended minimum flow for the Rainbow River System. The Rainbow River System is defined as the river reach from the Rainbow Springs Group (head waters) to the confluence with the Withlacoochee River, as well as all springs discharging to this reach.

The DRAFT technical report is divided into 9 chapters:

CHAPTER 1 – INTRODUCTION TO MINIMUM FLOWS AND LEVELS AND THE RAINBOW RIVER SYSTEM

CHAPTER 2 – HYDROLOGIC EVALUATION OF THE RAINBOW RIVER WATERSHED

CHAPTER 3 – WATER QUALITY OF THE RAINBOW RIVER SYSTEM

CHAPTER 4 – ECOLOGICAL RESOURCES OF THE RAINBOW RIVER SYSTEM

CHAPTER 5 – ENVIROMENTAL VALUES THAT MUST BE CONSIDERED WHEN DEVELOPING MINIMUM FLOWS

CHAPTER 6 – MINIMUM FLOWS DEVELOPMENT METHODOLOGIES

CHAPTER 7 – MINIMUM FLOWS DEVELOPMENT RESULTS

CHAPTER 8 – RECOMMENDED MINIMUM FLOW AND MINIMUM FLOW REEVALUATION, IMPLEMENTATION, AND COMPLIANCE

CHAPTER 9 – LITERATURE CITED

The peer review is comprised of the following 6 tasks:

1. *Determine whether the conclusions in the report are supported by the analyses presented.*
2. *Review the relevant data and information that supports the conclusions made in the report to determine if the data and information used were properly collected; if reasonable quality assurance assessments were performed on the data and information; if exclusion of available data from analysis was justified; and if the data used was the best information available.*
3. *Review the technical assumptions inherent to the analysis used in the Rainbow River System MFLs report to determine whether the assumptions are clearly stated, reasonable and consistent with the best information available; whether the assumptions were eliminated to the extent possible, based on available information; and if other analyses that would require fewer assumptions but provide comparable or better results are available.*
4. *Review the procedures and analyses used in the Rainbow River System MFLs report to determine whether the procedures and analyses were appropriate and reasonable, based on the best information available; if the procedures and analyses incorporated all necessary factors; whether the procedures and analyses were correctly applied; if limitations and impressions in the formation were reasonably handled; whether the procedures and analyses are repeatable; and if conclusions based on the procedures and analyses are supported by the data.*
5. *If a proposed method is not scientifically reasonable, the Panel should: list and describe scientific deficiencies and, if possible, evaluate the error associated with the deficiencies; determine if the identified deficiencies can be remedied; describe the necessary remedies; or identify one or more alternative methods that are scientifically reasonable.*
6. *If a given method or analyses is scientifically reasonable, but an alternative method is preferable, the review Panel should list and describe the method(s), and include a qualitative assessment of the effort required to collect data necessary for implementation of the alternative method(s).*

As background, the Panel reviewed a number of supporting documents, published reports, previous peer reviews of other MFLs reports, and submittals from stakeholders. Of importance was the HGL 2013 report—*Groundwater*

Flow Model for the Northern District Water Resources Assessment Project Area, Version 4.0 and HGL and Dynamic Solutions, LLC 2015 report: *Northern District Groundwater Flow Model Version 5.0,* which provided the conceptualization and technical basis of the groundwater flow model used to estimate groundwater impacts to the Rainbow River System.

CHAPTER 1 provides the legal directives for establishing MFLs, the methodologies used by the District for establishing MFLs, an overview of MFL development, criteria that the District uses for evaluating "*significant harm*," and a description of the Rainbow River System. Quantifying a minimum flow threshold is complicated because many components of flowing ecosystems vary incrementally with no clear "break-points". The Rainbow River System draft report continues the Districts practice of using a 15% loss of habitat availably as the threshold to define "*significant harm*". The basis for the District's MFLs rationale is built on the analyses and in other scientific literature previously reported and summarized by Flannery and others (2002) and peer reviewed by Gore and others (2002).

There are a number of approaches for setting freshwater inflow requirements. The District continues the practice of using a "percentage-of-flow" method for determining minimum flows for rivers and associated spring system. The percent-of-flow method identifies flow reductions as percentages of "natural flow" that may be withdrawn directly from the system without causing "*significant harm*. "Natural flow" is defined as the flow that would be expected in the absence of withdrawal-related impacts. Spring flow is volumetrically relatively stable for the Rainbow Springs System; therefore, the District authors did not partition spring flow using seasonal time steps.

A general geographic, geomorphic, and hydrologic description of the Rainbow River System and springshed was provided. The groundwater contributing area is about 640 mi^2 and located in parts of Alachua, Levy, and Marion Counties. The Rainbow River System consists of a spring group forming the head waters of Rainbow River and ending at the confluence with the Withlacoochee River. Collectively, Rainbow Springs is a first-order magnitude spring, fourth largest in Florida, and a major tributary of the Withlacoochee River. The Rainbow River System has state and federal recognition, designated as both an Outstanding Florida Water and a National Natural Landmark. Water clarity is over 200 ft in the upper reaches decreasing to 50 ft in the lower reaches. The annual river stage varies less than one foot with an absolute range of 3 ft over the period of record. The annual range in flows vary by about a factor 2.

Anthropomorphic alterations have impacted the Rainbow River System and springshed. Located about 12 miles downstream from the confluence with the Withlacoochee River, operation of Inglis Dam significantly affects the Rainbow River stage due to backwater effects. It is reported that removing the Dam would lower the stage in the lower reaches by as much as 8 feet. Changes in land use in the springshed have negatively affected the overall health of the Rainbow River system. Presently, the springshed is about 70 % agriculture and upland forest (rural).

DISCUSSION

Recurrently "*significant harm"* is set at 15% loss of habitat availably in MFL proposals; however, the suitability (or correctness) for protecting the resource and environment is unproven and needs defensible confirmation and validation. Furthermore, the report does not discuss other, possibly more stringent standards of "*significant harm"*. The Panel considers the adoption of a 15% threshold in the reduction of habitat availability from current or baseline conditions is presumptive and unverified based on the data presented in the Rainbow River System report. Furthermore, an argument for a more stringent standard is defensible given state (Outstanding Florida Water) and federal (National Natural Landmark) designations conferred on the Rainbow River System. Except in the rare case where a "tipping-point" threshold exists, there is little scientifically informed guidance. Ultimately this is a policy decision; however, the Panel suggests additional discussion as to why other, possibly more stringent, standards of "*significant harm*" were not considered.

The District selected to use a percentage-of-flow methodology that sets limits on groundwater pumpage as a proportion of river flow over its entire flow regime. This approach for establishing *MFLs* assumes linearity in environmental responses which is hardly ever true of hydrologic variables. The impacts from employing this approach should be independently verified. Over a 50-year period of flow records the mean daily discharge range from a minimum value of 470 to a maximum of 1060 cfs. Application of a linear percentage-of-flow determination merits further exploration of the effect of a smaller permissible flow reduction at lower flow when the springs are discharging less.

CHAPTER 2 provides the description and data analyses of the hydrogeology, hydrology, rainfall, water use, spring flow and ratings, and the groundwater flow model used to predict impacts of groundwater withdrawals on flow to Rainbow Springs Group. Also included are results of a water budget analyzed using the period of record mean annual discharge from the springs. Available data potentially used in analyses are summarized in appendix B including well stage and discharge, water quality, sediment, soils, and vegetation. This document provides a synopsis of data and analyses included in the MFL report and needed enhancements to report content suggested by Panel members.

Hydrogeologic Framework:
Conceptual model or hydrogeologic framework of the study area includes a surficial aquifer, a discontinuous intermediate confining unit, and a thick carbonate Upper Floridan aquifer. The surficial aquifer is not continuous due to a thin and often breached clayey intermediate confining unit.

Precipitation Stations:
Rainfall data from the Brooksville, Inverness, and Ocala NWS stations were compiled. Graphical analyses of rainfall data including 20-year moving average, departure from average for the period 1930-2014, and annual departure using springshed-wide, radar-estimated rainfall for the period 1995-2014 are presented. The 80-plus-year average rainfall is about 54 in/yr with an increasing 20-yr moving average “accumulation” until the mid-1960s and then decreasing since that time. This is consistent with multi-decadal cycles associated with the Atlantic Multidecadal Oscillation (Kelley and Gore, 2008). Since 1989, rainfall in 18 out of 26 years have been below average. Since 2012, however, rainfall has been above average.

Rainbow Springs Group Discharge and Groundwater Levels:
Discharge data for Rainbow River at Dunnellon (gage) for the period 1917-2014 were compiled. Annual, semiannual, monthly, bimonthly, and quarterly discharge measurements are available for the period 1917-present. Since 1965 mean daily discharge at the gage is estimated based on a relation between groundwater level in Rainbow Springs Well near Dunnellon and measured flow at the gage. The median flow of the Rainbow Springs Group is 694 ft^3/s for the period 1929-2014. Graphs presented in the draft MFL report shows spring flow progressively increasing from 1930 to about 1965 and then decreasing over the subsequent 49 years. Since 2012, the annual average flow has increased since recording its low of 502 cfs in 2014.

In 2000, a change in the relation between groundwater level in the well and flow at the gage is observed. In general, measured flows are 50-100 cfs lower after 2000 given the same water-level altitude in the Rainbow Springs Well prior to 2000 (fig. 1). The Panel has concerns about assertions that spring flow since 2000 was anomalously low vis-à-vis rainfall deficits. The hydrologic data provided by the district and our analysis confirm a break in slope beginning in 2000. Given the significance of this break, and the potential relevance to the north Florida system (i.e., including domains outside Rainbow Springshed), this double mass analysis (fig. 1) warrants inclusion in the MFL report.

Fig. 1 – Reconstruction of the double mass analysis provided by the SWFWMD. Shown are the residuals from a linear fit to the double mass (rainfall vs. runoff) curve, indicating a marked shift in 2000. On average during this period, Rainbow River is flowing at ca. 100 cfs below expectation.

Groundwater Pumping:
Estimated and metered annual water use for the period 1992-2014 were compiled and ranged from a low of about 14 Mgal/d in 1992 to about 28 Mgal/d in 2006. Since 2006, pumpage has decreased by about 10 Mgal/d.

Water Budget:
Assuming no change in storage the budget was quantified using a single value equal to the 50-year period of record mean annual discharge and equivalent recharge. Furthermore, applying the 2014 annual groundwater pumpage (17.6 Mgal/d) and assuming a consumptive use of 45%, the water budget analysis resulted in a flow reduction of 1.7% due to current pumpage.

The Panel thinks this water budget is overly simplistic. The influence on water budget from rainfall trends are compelling, and, after adjusting for ET (approx. 35"/yr), suggest that recharge may vary by 50% or more between maximum and minimum rainfall periods. Expanding the water budget discussion in the MFL report is needed. The Panel recommends that prior to deciding on the MFL, the District prepare a very detailed and comprehensive water budget that both accounts for the observed flow history of the spring system and provides confidence in prediction of future flows and water levels with and without increased consumptive use.

Numerical Models:

The Northern District Groundwater Flow model, Version 5.0 was used to evaluate impacts of groundwater pumpage on Rainbow River flows. The numerical model is calibrated to steady state (1995) and transient (1996-2006) conditions. The model also was verified for 2010 steady-state conditions. While the level of model documentation detail is cursory and insufficient for peer review purposes, based on documents reviewed by the Panel, the model is appropriately conceptualized and calibration statistics generally are within acceptable modeling standards. The calibration procedure was well-formulated and consistent with groundwater flow model guidelines. The model is a useful tool for the District to evaluate ***regional stresses*** (bold for emphasis) on the system at average annual, quarterly, or monthly time steps (Kuniansky, 2016). The uncertainty in model predictions could be reduced through independent verification by additional statistical analyses (see Grubbs, 2011).

Karst aquifers differ from other porous media aquifers due to porosity enlargement through limestone dissolution. The existence of conduits in the Upper Floridan aquifer does not mean that on average turbulent flow is dominant, but this should be investigated more fully in the future. The District should consider the unique plumbing of first-order magnitude springs (conduit turbulent flow) incorporating the dual permeability flow characteristic of karst aquifers and flexible mesh grids. The advantage of flexible mesh grids over traditional rectilinear grid, is ability to replicate (represent) greater detail (smaller scale features) where hydrologically essential. These may include simulation of wells, spring vents, and steep potentiometric surface gradients. Dual porosity can be numerically simulated using MODFLOW with the Conduit Flow Process (CFP) package (http://water.usgs.gov/ogw/cfp/cfp.htm), FEFLOW with Discrete Feature Elements (http://www.feflow.info/fracture.html), and MODFLOW Unstructured Grid (USGS) with the Connected Linear Network (CLN) Process (see http://water.usgs.gov/ogw/mfusg/). FEFLOW and MODFLOW USGS both offer flexible mesh capabilities for discretizing model domains.

Groundwater flow model results suggest spring discharge has decreased about 7 cfs (or 1.2 and 0.9 percent less in 2010 and 2014, respectively) due to pumpage. These reduction percentages somewhat agree with the water budget analysis but additional lines of evidence are needed in the MFL report to support these values.

Interplay of Hydrologic Variables:

The report could benefit from additional statistical analyses and time series plots of rainfall, discharge and pumpage along with time series plots of the ratio of discharge to rainfall and annual discharge/rainfall graphs. Additionally, to estimate the significance of the time trends in the flow of Rainbow River, a multivariate, locally-weighted scatterplot smoothing, (LOWESS; Cleveland and others, 1988) regression model to estimate flow of the Rainbow River is suggested (Grubbs, 2011). A more though assessment of climatic factors affecting spring flow also is suggested (see Weeki Wachee MFL report SWFWMD, 2008).

Quantification of the recommended minimum flow for the Rainbow River System requires evaluation of the historical spring discharge measurements used during development of hydrologic models. One area of concern is the stability of the discharge rating for the Dunnellon gage. Since 1965, the USGS has calculated mean daily discharge at the Rainbow River near Dunnellon gage using a rating relating groundwater level and spring discharge. Confounding the estimates of flow is a transient discharge rating and backwater effects from the Withlacoochee River. For this reason, it is recommended that the stability of the discharge rating and effects of backwater on rating-curve development be investigated (e.g. German, 2009). The stability of the discharge rating is essential to both the analysis and interpretation of the hydrologic record and its proper application of the biological and environmental criteria. The Panel also finds the 2000 flow anomaly a potentially interesting harbinger of change. Resolution of the origins of proposed anomalies by *vegetation drag* similar to Silver Springs, downstream head boundary conditions, or other factors, is critical to defensibly conclude that the Rainbow River System is, in fact, not impaired and in need of a recovery plan. We appreciate that analysis being deferred to the next iteration of this standard, but it should be clear in the report that this is a known knowledge gap, and that remedying that gap is a District priority.

Springshed Delineation-- The report provides several different maps for the springshed (e.g. fig. 1-2 vs. 2-15, which contrast at the edges with the time-series of springshed polygons provided by District staff); this is both confusing and somewhat revealing. The delineation of groundwater basins is extremely challenging given the paucity of data and the potential for climate and consumptive use to incrementally alter those boundaries. The District maintains that the geographic boundary is relatively fixed, and maps subsequently provided support this contention, though the 1975 springshed is dramatically larger than the others, coincident with a period of higher flow. Also noted is a very large zone of nearly flat aquifer potentiometric surface between Rainbow and Silver Springs that makes the edge detection extremely tricky. Variance in multiple realizations of the springshed polygon after omitting even single wells in this area might be instructive. The Rainbow River and Silver Springs Systems are hydrologically connected and therefore the Panel recommends future revisions of the MFL standards be considered conjointly. It was expressed by District staff that this coordination in ongoing and vigorous, and for that the Panel applaud both Districts. However, it's still not clear to the Panel whether this includes a joint determination of changing flows using a more expansive view of regional pumping impacts.

CHAPTER 3 describes nutrient levels and an analysis of the relation between flow and $N0_3$-N concentrations in the springshed. Appendix B provides supporting water-quality data along with other hydrologic, sediment, soils, and vegetation data. Although the overall water quality is considered good, nitrates in Rainbow Springs have steadily increased over the past 50 yrs from less than 0.1 mg/L in the 1940's and 1950's (Odum 1957; Jones and others, 1996) to about 2.0 mg/L in recent years. This is consistent with studies of other spring systems in Florida. FDEP has placed the Rainbow Springs Group and Run on the verified list of impaired waters due to excessive algae growth (algae mats) that has been correlated to elevated levels of nitrate (> 0.6 mg/L) in groundwater. Much of the nitrogen in groundwater is reported to be from prior land use or practices that no longer exist. Nitrogen and phosphorus are the major nutrient groups monitored for the Rainbow Springs System. Neither phosphorus or total phosphorous has shown an increasing trend and levels remain close to concentrations measured in the 1950s.

DISCUSSION

In general, the Panel found the water quality WRV section to be overly simplistic. The absence of a significant correlation between flow and nitrate concentration is salient, since nitrate is already roughly 6 times the numeric standard (0.35 mg N L^{-1}), but this is by no means the only way that flow impacts water quality. One key correlation in springs across the state is between flow and dissolved oxygen, with potentially important ecological impacts via effects on invertebrate algal grazers as well as mobilization of redox sensitive solutes like iron. We note, however, that Rainbow River has consistently among the highest DO levels of any of the major springs, so that correlation may be less significant.

Based on the content of the MFL report and personal observations during site visit to Rainbow Springs, elevated nutrient levels are a principal threat to the environmental integrity of this water body. While the correlation between flow and nitrate concentrations is not statistically significant (it barely misses that threshold), after removing the temporal trend, the sign of that relation (negative) clearly supports a trend toward lower concentrations with higher flow; therefore, if loads remain constant, concentrations may increase as flows decline. Moreover, the literature documents that flow declines increase residence time for nutrients. Nutrient loading is clearly of concern necessitating a good understanding of the spatial variation in loading rates from the springs over the springshed.

The District needs to explicitly state in the report the water-quality implications of the proposed MFL. The District did not include any water quality criteria in the determination of the minimum recommended flow for the Rainbow River System. The Panel recommends additional analyses to ensure that the proposed MFL will not result in exceedances in relevant water-quality standards or enhance algal growth. Typically, MFLs do not consider factors such as a TMDL. However, in this system nutrient loading is relevant to the MFL in that it can lead to vegetation changes (increased SAV) which in turn lead to hydrologic changes (reduced flow relative to aquifer head). It appears that the District has not yet resolved all the causal relations of interest to explain the change in flows, but nitrate concentrations are a candidate factor. The Panel is sympathetic to the relative absence of data for these sorts of determinations, but it's only by documenting these knowledge gaps formally in reviews like this that future knowledge acquisition efforts are motivated. In the absence of key supporting data, the District should consider capping withdrawals at current levels (or with a minimal allowable increase) until the nutrient issues are effectively addressed. In particular, consideration should be given to allow no reduction in flow unless there is a corresponding decrease in loading so that there is no net increase in projected nitrate concentrations. If this cannot be done, the District needs to be explicit as to the water-quality implications of the proposed MFL. Underlying this recommendation is our perception that the system, while still in relatively good shape, is substantially overused to the point that any reduction in flow could impact water quality and should be of concern. Specific issues requiring expanded discussion in the report include:

1) **<u>Integration of coves (and chlorophyll a) into the MFL</u>**

A unique feature of the Rainbow River system are old phosphate pits that adjoin the river, and, in some cases receive river water inputs. These coves are potentially important aquatic systems in their own right, and have been shown vulnerable to significant phytoplankton accumulation. Indeed, during the field tour, it was visually clear that return flow from Blue Cove was greatly enhancing chlorophyll a concentration in the river. Research work at UF conducted over the last two years suggests that the coves are a net source of chlorophyll a (though notably <u>not</u> of phosphorus), and that the flow rate into and out of the largest cove, which averages ~2 m^3/s (just over 10% of river flow) varies strongly with river stage (fig. 2). Given that mean flow rate, the residence time of water in that cove is nearly 60 hours, more than enough to allow proliferation of a phytoplankton community given high mineral nutrient concentrations in the river water. A decline in river discharge will lengthen the residence time in the cove, and this, in turn, will enhance chlorophyll a concentration in the water returning to the river. Insofar as this is a degradation of water quality, it seems to warrant further consideration.

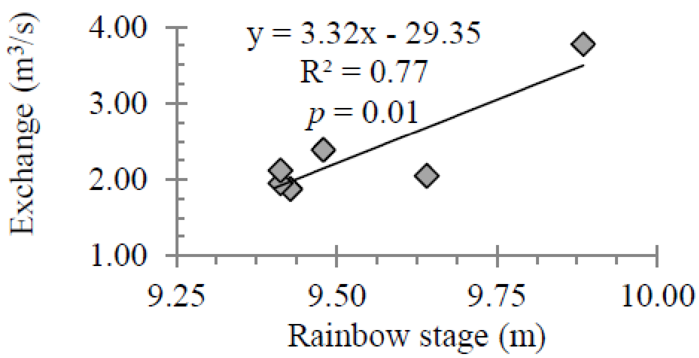

Fig. 2 – Rainbow River stage vs. measured flow rate into Blue Cove (Cohen et al. 2016). The strong positive association suggests that under reduced stage and flow conditions in the river, the water in the coves will be flushed less readily, potentially leading to greater chlorophyll a concentrations and reduced water quality when that cove water returns to the river just downstream.

2) **<u>Algal accumulation</u>**

The MFL must address a variety of water resource values, and one major ecological change observed in Rainbow River, particularly in the lower reaches, is the accumulation of filamentous algal mats, and the commensurate decline in submerged aquatic vegetation (as well as increased dominance of Hydrilla verticillata, an invasive exotic). While the provenance of these ecological changes is not entirely clear, and likely a response to several overlapping stressors, one emerging theme in the springs literature (e.g. King, 2014) is that flow velocity plays a significant role in algal cover. Where velocities are high, algal cover tends to be low, and while algal cover can vary dramatically at low velocity, proliferation of mats that smother SAV is clearly possible. It was therefore a surprising to see consideration of this algal proliferation issue not mentioned. Given that the link with discharge is direct, it warrants explicit mention in the report, even if the finding is that insufficient data exist to establish the link for this system.

Likewise, the loss of SAV is at least anecdotally linked to tubers standing on the bottom and dislodging the plants from flocculent sediments. Because recreation and benthic habitat are both water resource values, it seems relevant to consider this link explicitly. Again, we are sympathetic to the relative absence of data for these sorts of determinations, but it's only by documenting these knowledge gaps formally in reports like this that future knowledge acquisition efforts are motivated.

3) **<u>TMDL on the Withlacoochee River</u>**

Another peculiar feature of the Rainbow River is that the sediments transition longitudinally from coarse sands in the upper river to dense phosphatic clays in the lower river, a legacy of active phosphate mining that occurred in the area between the 1880's and 1930's. As a result of the change in texture and the change in mineral composition, the sediments in the lower river are a massive source of P to the river, increasing the P concentration from roughly 20 µg L^{-1} at the head spring to over 150 µg P L^{-1} by the confluence with the Withlacoochee. There is no numeric nutrient standard for P for springs or spring rivers, but the existence of TMDLs for downstream waters makes this rise in concentration a significant potential impact. The link to flow is simple dilution. More discharge means the benthic fluxes increase the riverine concentrations less.

4) **<u>Dissolved Oxygen</u>**

One key correlation in springs across the state is between flow and dissolved oxygen, with potentially important ecological impacts via effects on invertebrate algal grazers as well as mobilization of redox sensitive solutes like iron. We note, however, that Rainbow River has consistently among the highest DO levels of any of the major springs, so that correlation may be less significant.

CHAPTER 4 briefly summarizes the flora and fauna information found in the study area from the Rainbow Springs State Park and Rainbow Springs Aquatic Preserve management plans (FDEP, 2002 and 2015). Discussion of the ecological resources, data provided, and information referenced in this chapter appeared to be obtained from reliable sources and suitably peer reviewed. No procedures or analysis are provided in this chapter. The Panel has no comments or suggested revisions.

CHAPTER 5 summarizes the relevant ecological and water resource values (WRVs) that were considered when quantifying the recommended MFL for the Rainbow River System. These 10 are:

1. *Recreation in and on the water;*
2. *Fish and wildlife habitats and the passage of fish;*
3. *Estuarine resources;*
4. *Transfer of detrital material;*
5. *Maintenance of freshwater storage and supply;*
6. *Aesthetic and scenic attributes;*
7. *Filtration and absorption of nutrients and other pollutants;*
8. *Sediment loads;*
9. *Water quality; and*
10. *Navigation*.

The Rainbow River is not tributary to an estuarine environment thus WRV 3 was not considered to be applicable to this MFL project. WRV 5, Maintenance of freshwater storage and supply, and WRV 6, aesthetic and scenic attributes, were not individually considered by the Panel because the WRV is either inherently addressed through the MFL process or indirectly addressed in combination with other environmental values considered in this report. Neither methodologies nor analyses are described in this chapter. The Panel has no comments or suggested revisions.

CHAPTER 6 provides a discussion of the methodologies used to set the MFL for the Rainbow River System. The baseline condition as applied in the MFL report is the 1965-2015 flow record from Rainbow River near Dunnellon adjusted for historical groundwater withdrawals. The cap or threshold is "an allowable 15% loss of usable habitat". The application of hydraulic model analysis of potential flow reduction from baseline conditions are discussed (HEC-RAS and PHABSIM). The District combined several hydraulically related WRVs into the 4 criteria listed below.

- *Establishment of a low-flow threshold based on flows for fish passage and maintenance of water depths above lowest wetted perimeter inflection point* (e.g., maintaining the maximum amount of instream habitat quantity with the lowest rate of flow). This criterion is associated with recreation in and on the water (*WRV*-1), the maintenance of fish passage, fish and wildlife habitats (WRV-2), and navigation (WRV-10).

- *Protection of instream habitat for selected functional and taxonomic groups of fish and benthic macroinvertebrates*. This criterion is associated with fish and wildlife habitats (WRV-2), transfer of detrital material (WRV-4), aesthetic and scenic attributes (WRV-6), filtration and absorption of nutrients and other pollutants (WRV-7), and sediment loads (WRV-8).

- *Inundation of instream woody habitats, including snags and exposed roots, in the stream channel.* This criterion is associated with recreation in and on the water (WRV-1), fish and wildlife habitats (WRV-2), transfer of detrital material (WRV-4), aesthetic and scenic attributes (WRV-6), filtration and absorption of nutrients and other pollutants (WRV-7), and sediment loads (WRV-8).

- *Maintenance of seasonal hydrologic connections between the river channel and floodplain wetlands to ensure availability of inundated wetlands habitat and persistence of floodplain structure and function.* This criterion is associated with recreation in and on the water (WRV-1), fish and wildlife habitats and the passage of fish (WRV-2), transfer of detrital material (WRV-4), aesthetic and scenic attributes (WRV-6), filtration and absorption of nutrients and other pollutants (WRV-7), sediment loads (WRV-8), and water quality (WRV-9).

The HEC-RAS model, a commonly applied hydrologic tool for establishing the relation between streamflow and surface water elevation, was applied to the Rainbow River System and well-documented modeling procedures are found in Appendix C. The model input includes flows at the long-term gaging station and water elevations at 13 transects or cross sections. Linear interpolation was used to estimate flow values for the 13 cross sections. The HEC-RAS model was calibrated and validated using ten years of data (March 2005-March 2015). The model was considered calibrated when calculated water surface elevations were within plus or minus 0.5 ft.

HEC-RAS model results aided in selecting the recommended MFL for the system and used to determine the impact of flow reductions and associated surface water stage on fish passage, quantify change to habitat availability under various flow scenarios, and understand the duration of inundation in priority habitats.

PHABSIM, a biotic habitat model was linked to the HEC-RAS model and used in the fish passage and wetted perimeter analysis. The HEC-RAS output is used by the PHABSIM to determine the weighted usable areas or available habitat for various groups of fish and benthic macroinvertebrates, and delineate inundation areas. Using habitat suitability curves from PHABSIM, required minimum flows were quantified for 18 functional and taxonomic groups.

Two priority habitats identified and emphasized in the MFL report are Instream Woody and Floodplain Wetland habitats. Woody substrates are a critical habitat in most low gradient southeastern streams (Cichra and others, 2005). Frequency and duration of inundation (submerged) period are of critical importance in these habitats. Therefore, inundation duration requirements for these habitats were explicitly included in the MFL analysis.

Eleven instream woody habitat sites, live (exposed root) and dead (snag), were evaluated. Using the flow record from the Rainbow River near Dunnellon Gage, the inundation elevation of the exposed root and snag at the 11 sites were determined using the HEC-RAS model. Spread-sheet analysis subsequently was used to identify the number of days at baseline conditions that the specified inundation was equaled or exceeded at each site. Based on these analyses, the MFL recommendation was a threshold of no greater than a 15% reduction in number of days (duration) of inundation of the mean elevations of the instream woody habitats.

Assessing flow associated with maintaining floodplain wetlands involved long-term inundation analysis to identify the number of days during a defined period of record that a specific flow or level was equaled or exceeded. HEC-RAS coupled with HEC-GeoRAS were used to determine floodplain inundation patterns (frequency and duration) during baseline conditions. This data was then used for the baseline flow conditions and reduced flow scenarios to identify a maximum percent-of-flow reduction that would result in a 15% reduction in habitat availability.

DISCUSSION

The draft report provides a thorough and comprehensive discussion on the various biological components for development of minimum flows. The District efforts to focus on key habit indicators from fish and macroinvertebrate passage to sufficient inundation of instream woody and floodplain wetland habitats are appropriate. The Panel agrees with the District that these critical habitats need to be protected necessitating adoption of an inundation duration threshold as a MFL analysis component. The approach adopted by the District is reasonable and represents the best available information and is consistent with the District water policy.

Use of the various hydrologic models are suitable. The Panel agrees that the selection of a 0.6 ft minimum water depth for fish passage and a limit of a 15% reduction in the number of days of inundation is consistent with the stated definition of "*significant harm*" used in the draft MFL report. However, it is not clear why other, possibly more stringent standards of "*significant harm*" were not considered. At the public meeting, the Panel members advised caution in any use of a 15% reduction in habitat as a threshold beyond which further withdrawals would be significantly harmful. In this instance, given that the threshold is unproven and needs defensible confirmation, our concern goes to potential future application of the 15% threshold in setting other MFLs.

CHAPTER 7: The results of numerical modeling and findings from field investigations used to develop minimum flows criteria for the Rainbow River System are synthesized. Multiple habitat-based methods were used to evaluate relevant environmental values. Table and graphs were discussed in the context of the allowable 15% loss of usable habitat associated with a reduction in flow.

<u>Minimum Low-Flow Threshold</u>--Minimum low-flow threshold is defined as the minimum allowable discharge required to be protective of the environment (habitat) throughout the year. Head waters of the Rainbow River are formed by groundwater discharge and flows are more stable (less variable). This unique feature of spring fed rivers make determining a low-flow threshold difficult. Such is the case for the Rainbow River System. At current surface water withdrawals and potential future impacts from groundwater withdrawals on flows were found to be below the threshold recommended for this MFL. For example, the threshold surface water elevation (minimum channel elevation plus 0.6 ft) needed for fish passage criterion was exceeded for all flow reduction scenarios modeled. Additionally, the lowest wetted perimeter inflection point threshold was less the modeled elevation for the flow scenarios for all but one site. The lowest modeled flow of 507 cfs is sufficient to exceed minimum elevations for fish passage, allow for recreational use, and was sufficient to inundate all but one the 47 cross sections. This site required 622 cfs is to inundate the lowest wetted perimeter.

<u>PHABSIM Model Results</u>--The baseline condition flow record (1965-2015) was reduced by 5, 10, 15, and 20% and modeled using 3 backwater conditions of, 25% (low), 50% (medium), and 75% (high) with weighting values of 0.5 for medium and 0.25 for the low and high backwater conditions. In general, largemouth bass fry were the most sensitive group to reductions in flow.

<u>Results of Woody Habitat Inundation Analyses</u>—The number of days that the river water elevation was sufficient to inundate exposed root and snag habitats were examined at 11 instream cross section in the Rainbow River

System. Exposed roots at 3 sites were sensitive to reductions in flow of 20%. Averaging the allowable flow reduction for the 11 sites resulted in a 9% allowable flow reduction before the duration of inundation of exposed root habitat declines by more than 15%. Snag habitat was not sensitive to reductions in flow up to 20%.

Results of Floodplain Wetlands Habitat Inundation Analyses--Comparison of daily inundated floodplain wetland areas for the 1965-2014 baseline condition flow period and inundated areas for reduced flow scenarios indicate that a maximum 5% flow reduction could occur without exceeding a 15% decrease in the inundated area. A 4% reduction in baseline flows would be associated with a 15% decrease in inundated floodplain wetland habitat at the high range of flows (>10% exceedance); while 6% and 5% reductions in baseline flows would occur at the low (<90% exceedance) and medium (10-90% exceedance), ranges of flow, respectively. It also is reported that net decreases in water level elevation between the baseline flow and 5% flow reduction is "generally small" and changes in return frequencies associated with a 5% flow reduction are not expected to result in substantial change to the duration of inundated floodplain wetland habitat in the Rainbow River System.

DISCUSSION

The Panel found that the analyses were appropriate and reasonable, based on the best available information, and that the analyses were correctly applied. The overall assessments were thorough and include assessments of apparently all relevant habitat indicators, with the exception of water quality thresholds. Data synthesis techniques appear scientifically reasonable. The description of the use of the PHABSIM model is clear; however, more information should be presented to justify use of the weighting values associated with backwater conditions. Based on PHABSIM model results, a 9% flow reduction is protective of a 15% "*significant harm*" threshold while the maximum allowable flow reduction based on a 15% "*significant harm*" threshold in inundated floodplain wetlands habitat was 5%. Further discussion should be presented to justify the averaging the allowable flow reduction for the 3 PHABSIM sites (see table 7-2). Why not use the lowest maximum flow reduction of 6% determined at the PHABSIM 1 site?

CHAPTER 8 discusses the recommended minimum flow, minimum flow reevaluation, implementation, and compliance for the Rainbow River System. The analyses found largemouth bass and woody exposed root habitats were the most sensitive instream habitat to reductions in flow. The maximum allowable flow reduction based on a "*significant harm*" threshold of 15% decrease for the fish and woody habitat was 9%; while the allowable flow reduction based on a "*significant harm*" threshold of 15% in floodplain wetland habitat was 5%. The instream woody and floodplain wetland results were average to develop a minimum flow recommendation. In the end, the recommended minimum flow for Rainbow River System is a 7% allowable flow reduction or a maintenance of 93% of the baseline flow. The District recommends reevaluation of this minimum flow within 10 years.

DISCUSSION

For reasons that are not made sufficiently clear in the report, the decision was made to average the 9% flow reduction permissible for fish and woody habitat consideration, with the 5% reduction to significantly impact inundated floodplain area, yielding a permissible flow reduction of 7%. A clear and defensible justification for the selection of 7% is not provided in the report giving the impression that the selection was arbitrary rather than founded in scientific analysis. Allowing a 7% flow reduction would result in threshold exceedance of 15% reduction in *inundated floodplain habitat*. District staff have subsequently provided the Panel with a more thorough discussion of the rationale to support the 7% flow reduction threshold. Inclusion of this added material in the report would address this issue.

While the Panel is compelled by the District's argument that the stage decline associated with 5% vs 7% flow reduction is extremely small and well within the range of tolerance of taxa in other settings, the case of whether the effects of lowered stage in lakes with fringed cypress wetlands are analogous to stage decline effects in Rainbow River requires explicit explanation in the MFL document. Although the subsequent technical memorandum addresses the 7% rationale, the Panel believes that the District should proceed with a more conservative approach focusing on the most conservative value within the predicted range of values.

The Panel noted concerns with results of an alternative approach for minimum flows development for the Rainbow River (HSW Engineering, Inc., 2009) that yielded dissimilar results as those presented in the Districts MFL report. In the earlier report, the MFL evaluation was conducted using frequency analysis—an approach that has been successfully used by SJRWMD to defensibly implement MFLs on priority rivers in their jurisdiction. Results of HSW Engineering, Inc. evaluation are summarized below:

Water Resources Value (*WRV*)	Maximum allowable flow reduction without violating habitat threshold
1. Recreation in and on the water	Up to 5%
2. Fish and wildlife habitats and the passage of fish	Up to 5%
3. Estuarine resources	Not applicable
4. Transfer of detrital material	2 to 5%
5. Maintenance of freshwater storage and supply	Protected under all flow reductions
6. Aesthetic and scenic attributes	Up to 5%
7. Filtration and absorption of nutrients and other pollutants	Up to 5%
8. Sediment loads	2 to 7%
9. Water quality	Protected under all flow reductions
10. Navigation	Not applicable

The table above shows that the District's recommended allowable flow reduction of 7% for the Rainbow River System would not be protective of most of the WRVs. The frequency analysis approach reinforces allowable flow protection up to 5%, but not necessarily above that. Results of the frequency analysis approach also contradicts verbiage in the District's report that states *"this proposed minimum flow is protective of all relevant environmental values identified for consideration in the Water Resources Implementation Rule when establishing minimum flows and levels" (p.92)*. A thorough discussion of SWFWMD's MFL methodology results compared to HSW Engineering, Inc. MFL methodology results is suggested to address this concern.

Additionally, there was no analysis of uncertainty associated with numerical modeling efforts or the confidence level at which any analysis associated with "*significant harm*" was being applied. A thorough discussion of sources of uncertainty and confidence levels would be helpful additions to the report and would aid in interpreting the results.

FUTURE EFFORTS

While our overall assessment of the Districts effort is supportive, there are some key knowledge gaps that the report revealed that should be addressed and prioritized for future efforts. The Panel makes the following recommendations:

1. Investigating the flow anomalies as a function of downstream stage (in the Withlacoochee River or Lake Rousseau) was missing from the main body of the report. As mentioned elsewhere, the flow anomaly since 2000 strikes the Panel as critical. Resolution of the origins of that behavior, either by increased vegetation drag (as proposed in Silver Springs), downstream head boundary conditions, or other factors seem critical to conclude that the river is, in fact, not in need of a recovery plan. This is a known knowledge gap, and that remedying that gap should be a district priority.

2. It's the Panels opinion that the MFL for Rainbow River is sufficiently linked to the MFL for Silver River to warrant joint consideration. It was expressed by District staff that some this coordination in ongoing and vigorous, and for that the Panel applaud both districts. However, it's still not clear to the Panel whether this includes a joint determination of flow impacts. The Panel recommends that future revisions of the MFL standards be considered for Rainbow and Silver Rivers jointly with a more expansive view of regional pumping impacts.

3. The District needs to be explicit as to the water-quality implications of the proposed MFL and analyses should be carried out to ensure that the proposed MFL will not cause a violation of any relevant water quality standard or

cause an increase in algal growth. There are some knowledge gaps that should be prioritized for future efforts including:

Integration of coves (and chlorophyll-a) into the MFL—A unique feature of the Rainbow River system are old phosphate pits that adjoin the river, and, in some cases receive river water inputs. These coves are potentially important aquatic systems in their own right, and have been shown vulnerable to significant phytoplankton accumulation. A decline in river discharge will lengthen the resident time in the coves, and this, will enhance chlorophyll-a concentration in the water returning to the river. Insofar as this is a degradation of water quality, it seems to warrant further investigation.

Algal accumulation--One major ecological change observed in Rainbow River, particularly in the lower reaches, is the accumulation of filamentous algal mats, and the commensurate decline in submerged aquatic vegetation (as well as increased dominance of Hydrilla verticillata, an invasive exotic). While the provenance of these ecological changes is not entirely clear, and likely a response to several overlapping stressors, one emerging theme in the springs literature is that flow velocity plays a significant role in algal cover. Where velocities are high, algal cover tends to be low, and while algal cover can vary dramatically at low velocity, proliferation of mats that smother SAV is clearly possible. Given that the link with discharge is direct, it warrants further investigation.

TMDL on the Withlacoochee River--Another peculiar feature of the Rainbow River is that the sediments transition longitudinally from coarse sands in the upper river to dense phosphatic clays in the lower river, a legacy of active phosphate mining that occurred in the area between the 1880's and 1930's. As a result of the change in texture and the change in mineral composition, the sediments in the lower river are a massive source of P to the river, increasing the P concentration from roughly 20 µg L^{-1} at the head spring to over 150 µg P L^{-1} by the confluence with the Withlacoochee. There is no numeric nutrient standard for P for springs or spring rivers, but the existence of TMDLs for downstream waters makes this rise in concentration a significant potential impact. The link to flow is simple dilution. More discharge means the benthic fluxes increase the riverine concentrations less. Given that the link with discharge is direct, it warrants further investigation.

Dissolved Oxygen--One key correlation in springs across the state is between flow and dissolved oxygen, with potentially important ecological impacts via effects on invertebrate algal grazers as well as mobilization of redox sensitive solutes like iron. We note, however, that Rainbow River has consistently among the highest DO levels of any of the major springs, so that correlation may be less significant. Nevertheless, given the link with discharge, it warrants further investigation.

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Southwest Florida Water Management District. 2010. Anclote River System Recommended Minimum Flows and Levels. Ecological Evaluation Section. Resource Conservation and Development Department. Brooksville, FL

Southwest Florida Water Management District. 2010. Chassahowitzka River System Recommended Minimum Flows and Levels. Ecological Evaluation Section. Resource Conservation and Development Department. Brooksville, FL.

GENERAL COMMENTS AND ERRATA

1. Add List of Tables
2. Add List of Figures
3. Add Acronyms and Additional Abbreviations
4. Many sections of the report include generic text that adds little to the report (consider for example figures 2-3 and 2-4 and related text.) On the other hand, it is clear that District staff has done very useful work that is not documented in the report. It isn't essential to remove the generic materials though that would arguably improve the report, but we recommend adding some of the work already done, e.g. the double-mass analysis.
5. With just a few exceptions, the maps that show conditions for the entire spring shed are virtually illegible in the Rainbow River area and are of minimal value. We suggest replacing them with maps that focus on the area of interest. Those maps that are ok at the regional scale should have the location of Rainbow River identified. Figure 2-11 is a good example of what works well.
6. The extracts from Beecher and Seerley on Page 10 were very useful.
7. *Page 12, not clear what is meant by "vary incrementally with flow". Do you mean "vary continuously", in contrast to only changing at break-points?*
8. Page 12, see comments above about the use of citation for defending the 15% harm standard. There is no compelling scientific argument in these citations, and argument by precedent potentially ignores extenuating circumstances in Rainbow River (OFW designation, for example) that may justify a more stringent standard.
9. Page 13, suggest you make clear that the >200ft water clarity is horizontal.
10. Page 16, is the depth of lower Rainbow River such that there is 8 feet of freeboard available everywhere were Lake Rousseau to be drawn down?
11. Page 19, paragraph 2, line 1 – Only 7 regional groundwater basins are shown on figure 2-3.
12. Page 20, figure 2-3 – Add references Fisk (1983) and Healy and Hayes (1981).
13. Figures 2-8 and 2-10 combine to make me very concerned about allowing any reduction in flow.
14. Figure 2-8, Data on graph is from 1930-2014 not 1929-2014.
15. Why has spring flow not declined since 1990, when precipitation has continued to decline?
16. If spring flow has not declined, why does the recent period contain nearly ALL the lowest flows of record?
17. Would not a 7% decrease in flow potentially result in flows lower than any that have ever occurred historically (e.g. <500 cfs)?
18. Figure 2-10 contains two different Y axes, which is okay except there is no explanation in the legend.
19. Why has it been necessary to adjust the rating curve; and what does that tell us about how to interpret changes in flow over time?
20. Page 15, The northern basin and the springshed boundaries are important features of the analysis. It would be useful to present both in a figure so that the geometry of the domains is clear. Perhaps overlay the rainbow springshed on Fig. 2-14.
21. Page 15, Is there a citation to support the assertion and drawdown effects are most pronounced under confined aquifer conditions? Perhaps Williams et al. 2011?
22. Figure 3-1, are any of these sources important in the reach below the head springs?
23. Section 3.2, Suggest you describe the wastewater disposal practices for the extensive development along the river and indicate how that does or does not affect nitrate concentrations. Also, why nitrate concentrations decrease downstream.
24. Sounds like you have some chlorophyll-a data; if so, suggest you present and discuss.
25. Page 22-23, The cumulative departure figure for rainfall in the text on page 22 is not the same as in the figure on page 23.
26. Page 24, The time scales of the different plots are different. I recommend choosing a study period and sticking with that so that the geometry of the behaviors in different plots can be readily compared.
27. Page 25, Time-series regressions are enormously sensitive the first observation for detecting a trend. I recommend doing this regression starting each year from 1965 to 2000, and asking about the coherence in slope, sign, and significance across dates.

28. Page 27 –Because the water level change map does not comport with the springshed map, a plausible explanation is that the geometry of the springshed is changing with time. It would be valuable to look at the trends in the high recharge zone in the northwestern part of the basin (as inferred from materials sent after the initial meeting by District staff).
29. Page 28 – For this anomaly, it would be extremely helpful to consider plots of direct field measurements, and clearly distinguish this from plots using the flow derived from the USGS rating curve. It is still unclear to me whether discordance between measured flow and rating curve estimates of flow may explain some of the behavior since 2000. Wherever actual discharge measurements are used instead of rating-curve estimates, this should be made clear in the figure legend. Also, data for 1929 and 1930 should be removed from the figure since they are single measurements and do not represent average annual discharge.
30. Page 30, paragraph 1, line 1--add reference for Version 5.0
31. Page 32, need to set out the water budget in more detail. Consumptive use <50% is surprising given the high amount of agricultural use. The comment about a 2% reduction in ET should be quantified in terms of mgd or acre-feet; and something should be said about the circumstances in which that reduction would occur.
32. Page 34, did not understand how the various mgds for withdrawals compare – 20 mgd in Figure 2-16; 113 mgd in the last sentence on this page; >400 mgd in Table 2-3.
33. Page 53, five lines up from bottom – I wasn't sure which species was referred to by the term "This species".
34. Page 54, the term "prohibited" makes it sound like blocking manatee access is intentional. If that isn't the case, consider "prevented".
35. Page 58, section 5.9 – Need to justify the statement that reduced flow will not affect nitrate levels. Figure 3-5 shows a lot of scatter in the data, but a possible tendency to higher concentrations at lower flows; and from a mass balance perspective this should be the case overall.
36. Figure 6-1 – the shading patterns for the Lidar data need to be explained and the numeri's put in context.
37. Table 6-2 might benefit by indicating the range in the data (max and mins), so that the relative scale of the residuals can be appreciated.
38. Page 69, suggest you provide one example of the perimeter-flow plots.
39. Page 70, and one PHABSIM cross-section.
40. Page 82, This is one figure that may need to be discussed to explain why the effects of the 5% flow reduction are not considered important enough to be the basis for the MFL.
41. Appendices, there is a concern that there are lot of data sets that are not simply linear (e.g. Figures 3-10, 3-19) but that are presented without comment.
42. Page 38, Nitrite is not an "intermediate" form of nitrogen. It is a form that generally reacts quickly to nitrate or more reduced species under most environmental conditions.
43. Page 43, It's not clear why only nitrate data after 2000 was included in the analysis.
44. Page 44, This figure (for NO3 vs. Q) does support some dilution impact, even though the statistical tests barely miss the significance threshold.
45. Page 103, third authors last name has been omitted—should read Williams, Dausman, and Bellino, 2011.