Science Committee of the
Edwards Aquifer Habitat Conservation Plan

Scientific Evaluation Report:
Nonroutine Adaptive Management Proposal for the
EAHCP VISPO

April 12, 2019

Introduction

According to the Funding and Management Agreement, the Adaptive Management Science Committee (Science Committee) is tasked with evaluation of all Nonroutine Adaptive Management (AMP) proposals. These evaluations result in a "Scientific Evaluation Report" (SER) for presentation to the Stakeholder Committee. The Stakeholder Committee considers this report in their decision whether to recommend the Nonroutine AMP proposal to the Implementing Committee for final approval.

This SER is issued in response to the Nonroutine AMP proposal submitted by the Program Manager, dated March 14, 2019 related to the EAHCP Voluntary Irrigation Suspension Program Option (VISPO).

The SER was discussed and developed at the March 27, 2019 Science Committee meeting. EAHCP staff will seek approval of this SER shortly after and the report will be presented to the Stakeholder Committee at its meeting on May 23, 2019.

Nonroutine Adaptive Management Proposal

On March 14, 2019 the EAHCP Program Manager submitted a Nonroutine AMP Proposal to the Science, Stakeholder and Implementing Committees. It involves modifications to the EAHCP VISPO.

Scientific Evaluation of the Nonroutine Adaptive Management Proposal

The purpose of this report is to provide the Science Committee's evaluation of the proposed modifications to the EAHCP VISPO to meet EAHCP flow objectives. The EAHCP calls for four Flow Protection Measures to meet short-term and long-term flow objectives for the Comal and San Marcos springs complexes. The four measures include the VISPO, Regional Water Conservation Program, SAWS Aquifer Storage and Recovery (ASR), and Critical Period Management – Stage V.

The modeling analysis of these four Flow Protection Measures to support the EAHCP was performed using a layered approach to consecutively evaluate addition of each conservation measure on springflows. This layered approach is referred to as the "Bottom-Up" package. Table 1 describes the maximum amount of water conserved through each of the Flow Protection Measures for a given year. Details of these measures can be found in the HCP, its appendices, and other associated documents (Table 1).

Tables 2 and 3 show the minimum and long-term average flow related objectives included in the EAHCP.

Table 1. Maximum annual volume (ac·ft yr^{-1}) of groundwater that can be conserved with EAHCP Flow Protection Measures.

Flow Protection Measure	Maximum Annual Volume Conserved	EAHCP Section
VISPO	40,000	5.1.2
RWCP	10,000	5.1.3
SAWS ASR FORBEARANCE	46,300	5.5.1
EAA FORBEARANCE OF SAWS ASR LEASES	50,000	5.5.1
STAGE I - V	44% Permit Reduction	5.1.4

Table 2. Long-term average and minimum total Comal discharge management objectives (Table 4-2 of EAHCP)

Description	Total Comal Discharge (cfs)[a]	Time-step
Long-term average	225	Daily average
Minimum	30[b]	Daily average

[a]Assumes a minimum of a 50-year modeling period that includes the drought of record
[b]Not to exceed six months in duration followed by 80 cfs (daily average) flows for 3 months

Table 3. Long-term average and minimum total San Marcos discharge management objectives (Table 4-13 of EAHCP)

Description	Total San Marcos Discharge (cfs)[a]	Time-step
Long-term average	140	Daily average
Minimum	45[b]	Daily average

[a]Assumes a minimum of a 50-year modeling period that includes the drought of record
[b]Not to exceed six months in duration followed by 80 cfs (daily average) flows for 3 months

The “Bottom-Up” package was originally evaluated by HDR to understand whether the Flow Protection Measures could meet EAHCP flow objectives (HDR 2011 – Appendix K EAHCP). The HDR Bottom-up analysis was conducted by simulating spring discharge over the period of 1947-2000 using the MODFLOW groundwater model developed by Lindgren et al. (2004). These model results indicated the Phase I Flow Protection Measures were not adequate to meet minimum and long-term average springflows in the Comal system. However, minimum and long-term average flow objectives were achieved in the San Marcos system.

During Phase I of the EAHCP, the original MODFLOW model used by HDR was reconstructed with several significant improvements (herein referred to as EAA model). Changes made during model construction along with calibration and validation results are described in detail by Liu et al. (2017). Additionally, further comment on model construction and its use can be found in the review by the EAA-appointed Groundwater Model Advisory Panel (Appendix Liu et al. 2017), the National Academies of Sciences (NAS) Reports 1-3 covering the EAHCP (NAS 2015; NAS 2017; NAS 2018), SAMP model inputs and assumptions by Pence (2018), and technical presentations delivered to the NAS panel and EAHCP Science Committee (www.eachp.org).

The EAA model and its outputs were reviewed by the NAS panel to make their determination on whether the EAHCP Flow Protection Measures would be adequate to achieve the EAHCP flow objectives. The panel concluded the measures would be “effective” at meeting the flow objectives citing the conservative nature of the low flow estimates, empirical evidence from the 2014 drought, and the EAA model’s ability to match observations during validation runs – especially during periods of low flow.

During Phase I, the EAA model was also used by EAA staff to reconstruct a Bottom-Up analysis using the same inputs and assumptions as the original HDR (2011) analysis. A difficulty encountered in reconstructing the Bottom-Up analysis is that the original analysis was conducted under the Edwards Aquifer Recovery Implementation Program (EARIP) prior to EAA taking on project management of the EAHCP and the original model files were not archived. Fortunately, EAA staff were able to obtain the archived files from a more recent Bottom-Up analysis by HDR (2015), which included a baseline analysis of the original 2011 model with a table of pumping rates for baseline conditions and for each of the Bottom-Up layers. Using this table of specified pumping reductions for each Bottom-Up layer, EAA staff was able to repeat the analysis and obtain minimum flow estimates for Comal and San Marcos Springs that were very similar to those reported in the original HDR (2011) report.

The next use of the Bottom-Up package by EAA staff was to conduct the Nonroutine Adaptive Management Model Runs described in the following section. For this analysis, the pumping assumptions were specified in the Pence (2018) memorandum. This process required EAA staff to reconstruct the baseline pumping and each of Bottom-Up layer pumping input files from scratch. During this process, it was discovered that the previous EAA Bottom-Up analysis that was intended to use the HDR (2011) pumping assumptions did not include 6,000 acre-feet of exempt federal pumping. Adding federal pumping to the analysis caused the estimated minimum flow for Comal Springs to drop by 6 cfs compared to the earlier analysis. Further analysis showed that adjustments to the schedule for SAWS ASR pumping forbearance, as described below, could be used to increase the estimated minimum flow at Comal Springs by the same amount as was lost by the addition of exempt federal pumping.

Nonroutine Adaptive Management Model Runs

Minimum Flow Objectives

The EAA MODFLOW model was executed with pumping and flow protection conservation measures previously described in Pence (2018). Briefly, geographic location and volume of forborne water via Flow Protection Measures are based on actual program enrollments, according to county and type of use. The annual base case pumping prior to any stage restrictions is 592,454 ac·ft yr^{-1} and is distributed geographically in the same manner as the HDR runs.

During development and testing of the model, it became apparent that a modified schedule of the SAWS ASR forbearance could increase minimum computed springflows during Drought of Record (DOR) simulations. In the HDR model runs, SAWS ASR pumping forbearance were guided by a schedule included in the Interlocal Agreement between EAA and SAWS for use of the ASR facility for springflow protection. This schedule was adjusted to maximize springflow benefit in accordance with SAWS guidance regarding the amount of Edwards water that could reasonably be forborne during any monthly stress period in a DOR scenario.

Limitations on monthly forbearance rates stem from the total pipeline capacity and the fact that forbearance cannot exceed what normal demand for Edwards water would be from the four pumping stations where the forbearance schedule is implemented. The first limitation is that total forbearance in any calendar year cannot exceed 46,300 ac·ft yr^{-1}. The limitation of monthly demand varies by month. The maximum reasonable forbearance rate for January is 3,500 acre-feet but this can be gradually increased to a maximum of 5,600 acre-feet for the high demand months of May through September. Revisions from the original schedule made in the current model scenario increase forbearance rates at the beginning of the year 1956, leading up to the period of minimum flow in August 1956, and decrease rates after September when the springflows start to recover. Table 4 displays changes to the SAWS forbearance schedule for the model runs discussed below.

Table 4. SAWS ASR forbearance representation in MODFLOW Drought of Record simulations.

Month In 1956	HDR (2011) (ac·ft)	Nonroutine AMP Runs (ac·ft)
January	1700	3200
February	1400	3500
March	1100	4500
April	2200	4500
May	3800	5600
June	5600	5600
July	5600	5600
August	5600	5600
September	5600	3000
October	5200	2000
November	4700	1700
December	3800	1500

Figure 1 displays MODFLOW model output for San Marcos and Comal springs with all Flow Protection Measures applied, minimum flow objectives for both systems, and modeled SAWS ASR forbearance. Minimum flows from the model simulation were 29.1 cfs in Comal and 48.1 cfs in San Marcos, both during the month of August 1956.

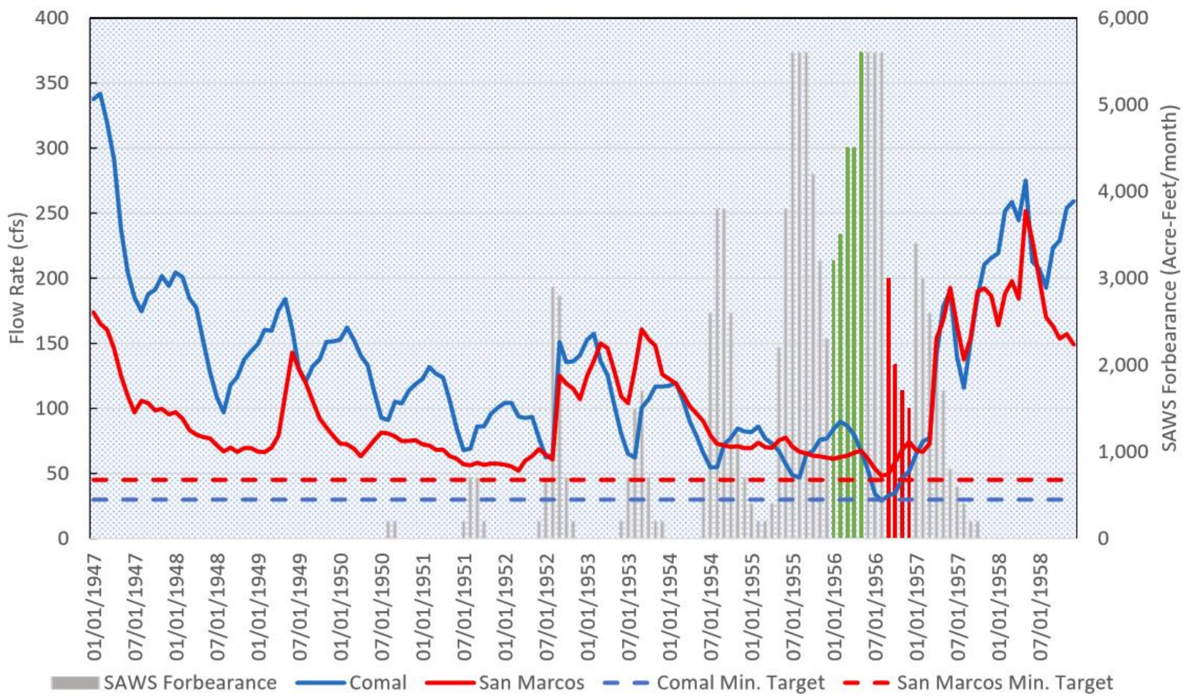

Figure 1. MODFLOW output for Drought of Record simulations at San Marcos and Comal springs. The green bars represent SAWS forbearance in excess of the original forbearance amounts shown in the Interlocal Agreement between EAA and SAWS for use of the ASR facility for the purpose of springflow protection. The red bars represent SAWS forbearance less than the original forbearance amounts shown in the contract.

To evaluate how much additional forbearance was needed to achieve the 30.0 cfs minimum flow objective at Comal Springs, forbearance through the VISPO was increased in the MODFLOW simulation from 40,000 ac·ft yr^{-1} until the flow objective was met. VISPO forbearance of 41,795 ac·ft yr^{-1} achieves the desired minimum of 30.0 cfs. Minimum flows for the San Marcos system with the adjusted VISPO number are 48.3 cfs. Results for the increased VISPO scenario are shown in Figure 2.

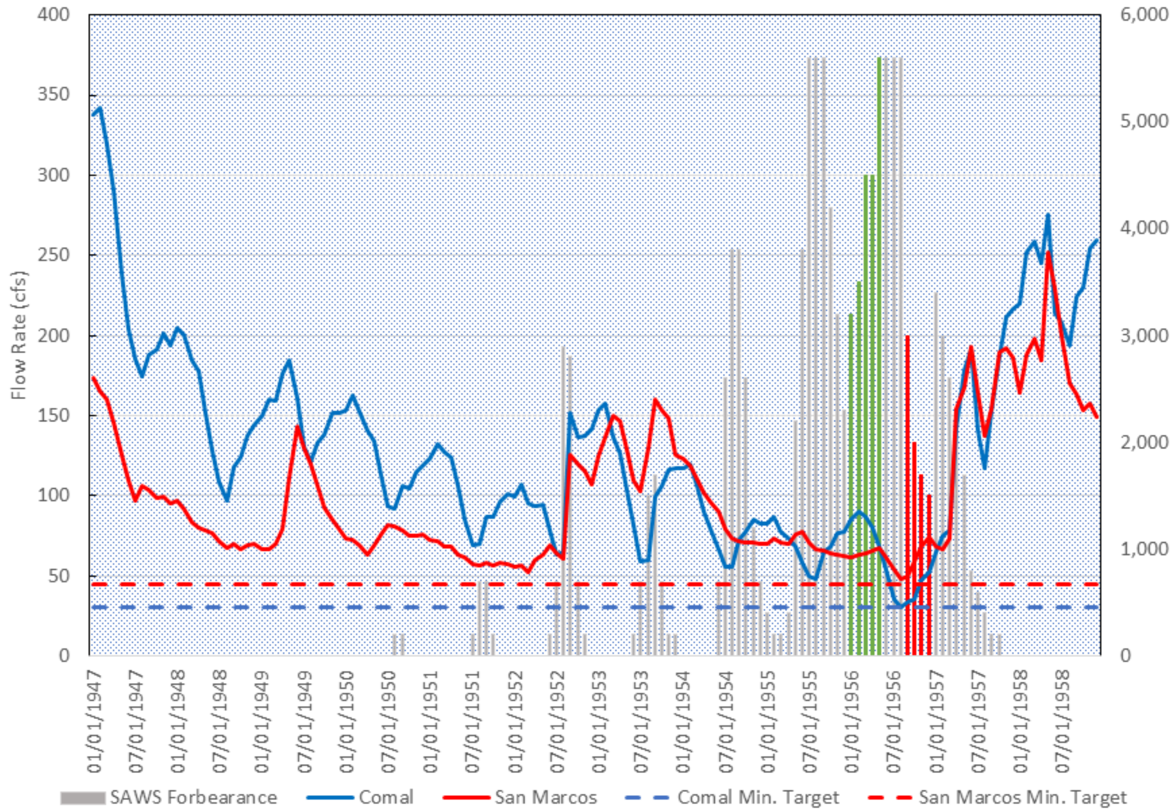

Figure 2. Same as Figure 1 with VISPO adjusted to 41,795 ac·ft yr^{-1}.

Long-Term Average Flow Objectives

HDR evaluated the ability of the Flow Protection Measures to meet the long-term average flow objective by modeling the period of 1947-2000 assuming an annual base case pumping of 593,240 ac·ft yr^{-1} prior to application of any conservation measures (see Pence 2018 or HDR 2011 for a description of HDR total pumping). Results from HDR indicated long-term average flow of 196 cfs in the Comal system, a 29 cfs deficit from the 225 cfs objective. The same analysis in San Marcos indicated a long-term average of 155 cfs exceeding the long-term flow objective of 140 cfs.

The 1947-2000 model period was not simulated with the EAA model for two primary reasons. First, unlike the HDR model, the EAA model was not calibrated to the 1947-2000 time period. The EAA model used a much more recent hydrologic record (2001-2011) for parameterization and calibration and was specifically built to accurately predict periods of low flows at Comal and San Marcos springs. It would not be expected to perform a multi-decade simulation as well as the HDR model calibrated over the time period in question. Second, using the total annual pumping offered in the HDR analysis dictates the long-term flow objectives are unachievable regardless of the model selected.

Examining the model from a mass balance perspective:

$$Recharge - Pumping - Springflow = \Delta Storage \qquad 1$$

If we consider a sufficiently long time period such that change in storage is negligible:

$$Recharge = Pumping + Springflow \qquad 2$$

If we insert the long-term average flow objectives (Comal: 225 cfs = 163,000 ac·ft yr^{-1}; San Marcos: 140 cfs = 101,355 ac·ft yr^{-1}), estimated long-term average outflow from other minor springs (80,000 ac·ft yr^{-1} - see Liu et al. 2017), and long-term average recharge (779,000 ac·ft yr^{-1}) into the above equation, the amount available for long-term average pumping is approximately 434,000 ac·ft yr^{-1} (Liu et al. 2017; EAA 2018a; EAA 2018b). By assuming 592,454 ac·ft yr^{-1} of annual pumping as the base case (before any permit restrictions) in the long-term simulation, the long-term average flow objectives cannot be reached.

To understand the ability to meet EAHCP long-term flow objectives over the remainder of the ITP, empirical data were examined. Using Equation 2 and fixing total springflow (San Marcos + Comal + minor springs) at the long-term averages discussed above (344,355 ac·ft yr^{-1}), recharge will equal pumping plus 344,355 ac·ft yr^{-1}. Given there are nine years remaining on the current ITP, we can examine the previous 41 years of the empirical hydrologic record and make conservative assumptions about the next nine years to estimate the fifty-year long-term average.

Recharge, including estimated interformational flows (estimated at 75,000 ac·ft yr^{-1}), over the past 41 years has been slightly over the long-term average at 908,000 ac·ft yr^{-1} (EAA 2018a; Liu et al. 2017). Over the same time period, total pumping estimates have averaged 410,000 ac·ft yr^{-1} (EAA 2018b). If we assume the following nine years are simultaneously the highest nine years of pumping ever recorded (none of which have occurred under management of the EAA) and the lowest 9 years of recharge ever recorded, the fifty-year average recharge would still exceed average total pumping plus long-term flow objectives (EAA 2018a, EAA 2018b).

It is important to note this synthetic combination of extreme pumping and recharge could not occur under EAA stage restrictions and EAHCP Flow Protection Measures. There appears to be no present threat of violating long-term springflow averages written into the EAHCP. However, more realistic terms should be constructed in future evaluations of these goals.

80 cfs footnote

Both springflow objective tables found in the EAHCP (Tables 1 and 2) contain a footnote on the minimum daily average flow objective that states “Not to exceed six months in duration followed by 80 cfs (daily average) flows for 3 months”.

The purpose of the flow pulse requirement was two fold: 1) an attempt to return flow to Spring Run 3 for macroinvertebrates and salamanders, which does not occur at flows less than 80 cfs according to data and the HCP, and 2) to accommodate another Fountain Darter spawn in the Old Channel ERPA by increasing flows and thereby maintaining suitable temperatures for a spawn to occur.

Under the proposed AMP, flows would not go below the minimum daily average flow objectives or “maintain” it for six-months. However, both systems would experience varying amounts of time between the minimum objective and the 80 cfs threshold identified.

Figures 3 and 4 display the DOR MODFLOW simulation for Comal and San Marcos springs, respectively, as shown in Figure 2 with total system flow (blue line), time steps with flow under 80 cfs (bar graph), and six-month moving averages when instantaneous flow was under 80 cfs (red lines). In the Comal during the ten-year DOR simulation, there are six instances where flow dips below and recovers above 80 cfs. The first three instances occur for 2 to 3 months and 6-month average flows remain over 80 cfs. The latter three instances have flows under 80 cfs for 6-11 months and 6-month average flows dip as low as 40 cfs.

In San Marcos during the ten-year DOR simulation, there are four instances where flow dips below and recovers above 80 cfs. The instances are lengthier (7-33 months) than the Comal and all four result in 6 month moving averages less than 80 cfs.

Figure 5 displays frequency graphs of maximum consecutive months under flows from 30 – 100 cfs for both spring systems. At Comal Springs, the lowest prolonged flows for 6 consecutive months is 53 cfs and under. For San Marcos, the lowest flows experienced for 6 consecutive months is 58 cfs and under. This proposed flow regime does not trigger the 80 cfs pulse requirement.

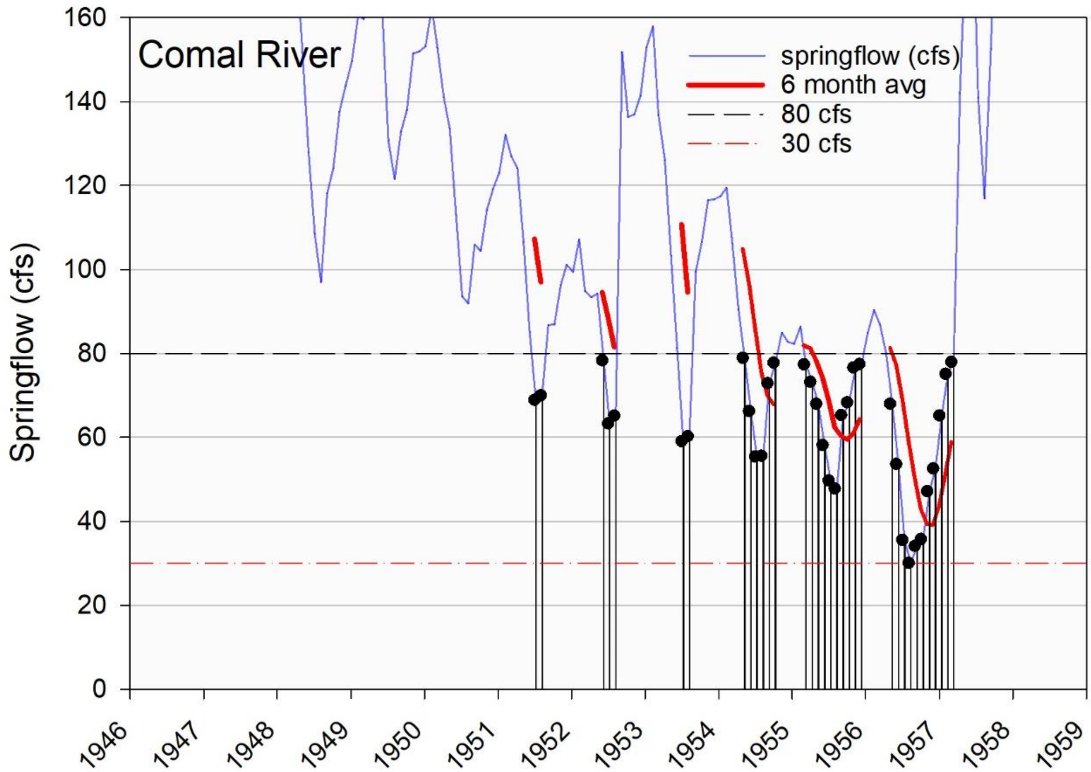

Figure 3. Comal Springs Drought of Record MODFLOW simulation shown in Figure 2 with periods of less than 80 cfs shown with bars. Other selected thresholds and statistics are shown.

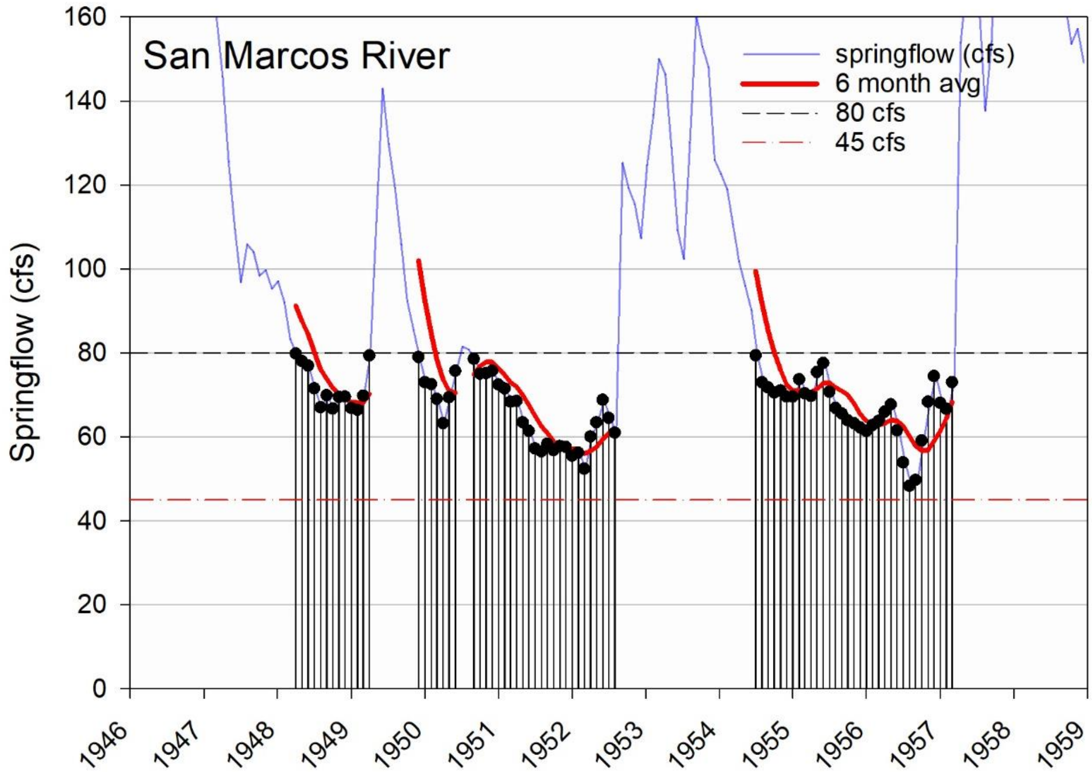

Figure 4. San Marcos Springs Drought of Record MODFLOW simulation shown in Figure 2 with periods of less than 80 cfs shown with bars. Other selected thresholds and statistics are shown.

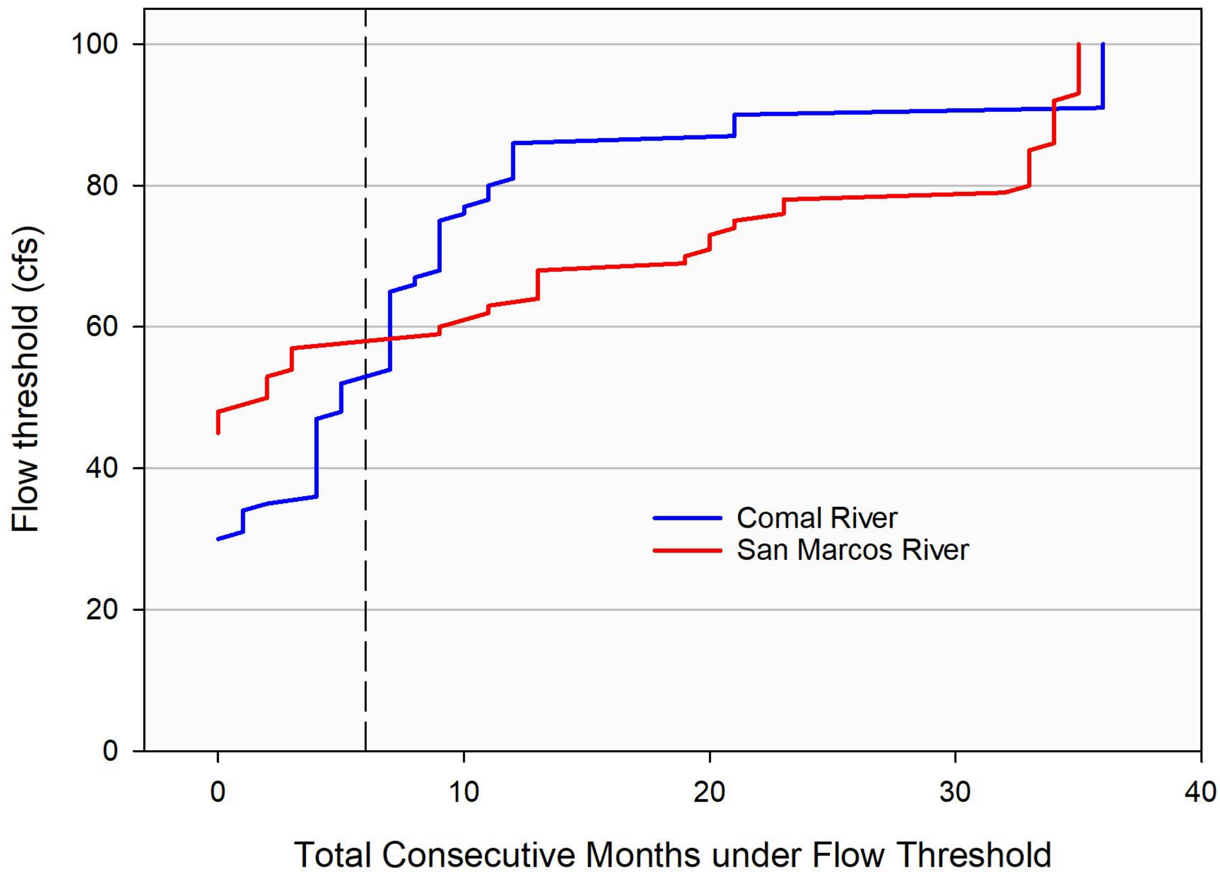

Figure 5. Frequency distributions displaying consecutive months less than flow thresholds. The vertical line is placed at 6 consecutive months.

Citations

Lindgren, R, A Dutton, S Hovorka, S Worthington, and S Painter. 2004. Conceptualization and simulation of the Edwards Aquifer, San Antonio Region, Texas: U.S. Geological Survey Scientific Investigations Report 2004-5277, 143 p.

Liu, A, N Troshanov, J Winterle, A Zhang, S Eason, 2017. Updates to the MODFLOW Groundwater Model of the San Antonio Segment of the Edwards Aquifer. Available at: https://data.edwardsaquifer.org/documents/2017_Liu-etal_UpdatestotheMODFLOWGroundwaterModeloftheSanAntonioSegmentoftheEdwardsAquifer.pdf.pdf

HDR, 2011. Evaluation of Water Management Programs and Alternatives for Springflow Protection of Endangered Species at Comal and San Marcos Springs. Available at: http://eahcp.org/wp-content/uploads/2019/02/Appendix-K.pdf

EAA, 2018a. 2017 Groundwater Recharge. Available at: https://www.edwardsaquifer.org/science-and-maps/research-and-scientific-reports/hydrologic-data-reports

EAA, 2018b. 2017 Groundwater Discharge and Usage. Available at: https://www.edwardsaquifer.org/science-and-maps/research-and-scientific-reports/hydrologic-data-reports

NAS, 2015. Review of the Edwards Aquifer Habitat Conservation Plan Report 1. Available at: http://eaahcp.org/administration/science-review-panel/

NAS, 2016. Review of the Edwards Aquifer Habitat Conservation Plan Report 2. Available at: http://eaahcp.org/administration/science-review-panel/

NAS, 2018. Review of the Edwards Aquifer Habitat Conservation Plan Consensus Report. Available at: http://eaahcp.org/administration/science-review-panel/

Pence, 2018. SAMP Model Runs Inputs and Assumptions. Memo to EAHCP Committees, June 21, 2018.

Summary of Science Committee Discussion of the Proposal

Overview

At the March 27, 2019 Science Committee, EAHCP Chief Science Officer Chad Furl provided a comprehensive presentation, *Nonroutine Adaptive Management: VISPO Flow Protection Measure* to the Science Committee. This presentation covered (1) the background to the AMP built into the EAHCP, (2) the history of Springflow Protection Measures and Flow Objectives, (3) the findings of MODFLOW output; and finally, (4) the elements of the Nonroutine AMP proposal itself.

The following sections provide a summary of the Science Committee's discussion of the Nonroutine AMP proposal, organized according to the main themes that emerged over the course of the discussion. This section concludes with the final motions (including associated final recommendations) made by the Science Committee concerning the Nonroutine AMP proposal and this Scientific Evaluation Report.

At the end of this section, are written comments submitted April 4, 2019 by Dr. Conrad Lamon of the Science Committee.

Science Committee Discussion

<u>Public Comment:</u>

Myron Hess, EAHCP Stakeholder Committee Chair, advised the Science Committee to expand the title of the VISPO proposal to include language that expresses that the effort to modify the flow protection measure is within the context of Phase II of the EAHCP and is intended to maintain compliance for the remainder of the program. Additionally, Mr. Hess recommended that a portion of the proposal include more information on ASR program and the changes that have been made by providing the process to which the modeling results were used and analyzed.

<u>VISPO Nonroutine AMP</u>

Dr. Chad Furl provided the Committee an overview of the Nonroutine AMP proposal and process to approve the modifications to VISPO. Dr. Furl reminded the Committee that the overall intent of the proposal is to achieve the minimum flow objective of 30.0 cfs at Comal Springs written into the HCP.

Dr. Charles Kreitler questioned if the updated SAMP DOR model run takes into account the modifications to both the VISPO and ASR Program. Dr. Furl confirmed that the latest model run includes both program updates, "as-implemented" forbearance measures, and 6,000 acre-feet per year of federal pumping to achieve 30.0 cfs at Comal Springs.

Dr. Jack Sharp asked, considering the additional 1,795 acre-feet in VISPO forbearance, how sensitive is the model to actual pumping locations. Mr. Jim Winterle responded that

there is some sensitivity to locations. For example, the springs respond quickly from the effects of forbearance in Bexar County. This response is delayed from forbearance in Uvalde County.

Dr. Sharp asked how the increase in VISPO forbearance was determined. Mr. Winterle explained that the change in forbearance results in an almost linear rate of increase in springflow. The forbearance number was simply adjusted until the minimum flow objectives were met. Increasing ASR forbearance rather than VISPO was considered but was determined to be too expensive.

Dr. Conrad Lamon asked if there has been any attempt to run the model with actual inputs rather than assumed scenarios. Dr. Furl explained that the model was calibrated in 2011 with the most recent hydrologic data at that time and then validated with hydrologic data from 2011-2015. Mr. Winterle added that the model was also validated with DOR data. The Liu et.al report captures the results of those model runs. Dr. Lamon expressed concerns over the lack of an uncertainty analysis conducted in development of the model. Mr. Winterle explained that the program is engaged with the USGS to conduct more formal uncertainty analysis, but the results of the uncertainty analysis will not be available until the end of the year. Dr. Lamon advocated that the results on the uncertainty analysis would provide a financial benefit to the program.

Dr. Jacquelyn Duke asked if refinements and adjustments can be made after the proposed modifications have already been approved. Dr. Furl clarified that the proposal is a solution for Phase II and the modifications will stay for the reminder of the permit. However, efforts to update models and review flow protection measures will continue.

Dr. Lamon further commented on details surrounding uncertainty analysis in the MODFLOW model.

Dr. Tom Arsuffi commented that the current issue regarding flow protection can be solved using the best available scientific data. Hopefully, further research and the product of the uncertainty analysis can provide information to help refine the model.

Dr. Kreitler commented that the EAA agreed to have a minimum flow of 30.0 cfs as a USFWS requirement. The modifications proposed will achieve the obligation.

Chad Norris asked if the additional VISPO water is currently under contract with EAA. Dr. Furl clarified that 40,000 acre-feet is what was stated in the EAHCP, and the 40,921 acre-feet is the amount currently under contract.

Dr. Duke added that the proposal is a very conservative effort to resolve the concerns regarding 30.0 cfs in Comal Springs.

Dr. Furl presented the long-term flow objectives and results from the empirical hydrologic record.

Chad Norris asked for clarification that although the models indicated that the long-term flow objectives will not be achieved, Dr. Furl was suggesting the mass balance equations

confirm that it is likely that the objectives will be met. Dr. Furl clarified that, based on the springflow data provided by the USGS, it is very likely that the objectives will be achieved using the mass balance equations. Mr. Winterle added that developing a model to analyze the long-term flow objectives was considered, however, the most realistic scenario isn't what was used in the model but rather, what actually occurred. Historical data will illustrate that the long-term flow objectives have been achieved.

Dr. Kreitler clarified that by using the model the long-term flow objectives will not be achieved, however, if you use observed data in a mass balance equation, the objectives will be met.

Dr. Kreitler raised the issue of the increase population in the I35 corridor and the effects it can have on water demand.

Dr. Furl discussed the 80 cfs flow objective and the referenced six month low flow time period footnote included in the EAHCP. Dr. Furl noted that the proposed AMP would authorize fluctuating flow rates between the minimum objective and the 80 cfs threshold without triggering the 80 cfs requirement.

Chad Norris commented that the purpose of the 80 cfs pulse flow requirement and six month minimum springflow time duration was included in the EAHCP with the intent to not subject the invertebrates to drought of record conditions for longer than six months.

Dr. Sharp asked Mr. Winterle the anticipated issues to arise and what, if any, should the models address. Mr. Winterle answered, in regard to applying for a 30-50 year ITP, the models should be prepared for the effects of climate change. Additionally, the primary concern today is the uncertainty of VISPO and maintaining compliance with the springflow protection requirements for the remainder of the ITP. Many of the long-term concerns will be addressed after Phase II and during the rollover period to the second ITP.

Final Motions by the Committee

Dr. Arsuffi made a motion to recommend the Nonroutine AMP proposal as presented. Dr. Sharp seconded. Dr. Conrad Lamon and Doyle Mosier abstained from voting. There were no further comments. All those not abstaining were in favor. Motion passed.

Dr. Weckerly made a motion to endorse the process to prepare and submit this Nonroutine AMP Scientific Evaluation Report via the Science Committee Chair and Vice-Chair to the Stakeholder Committee by May 23, 2019. Dr. Sharp seconded. All were in favor. Motion passed.

This draft of the Scientific Evaluation Report was approved by the Chair and Vice-Chair of the Science Committee for submission to the Stakeholder Committee on April 12, 2019.

EAA MODFLOW model updates

Lamon

March 27, 2019

“Validation results for Comal Springs (Figure 37) are similar in every respect to those of index well J17, which is expected given the strong correlation between observations at the two locations. The model underestimates flow by approximately 30 to 40 cubic feet per second (cfs) for most of the validation period, but does a good job to match the lowest observed flow in August 2014.” -Liu et al, 2017, Uncertainty Analysis section, page 54

Unfortunately, that's not how we determine prediction error. We estimate measures of model fit for a calibrated model, using data that were held out of consideration during the calibration process. We don't chose a point on the validation simulation run where fit was “good” and use that as our estimate. We take a measure that represents the aggregate fit over the entire validation run.

We have three MODFLOW runs to evaluate, two done by the EAA staff with their model (Liu et al, 2017) and one by HDR (HDR, 2011).

```
forbearance<-c(40000,40921,41795)
springflow<-c(29.1,29.6,30)
plot(springflow~forbearance)
abline(lm(springflow~forbearance))
```

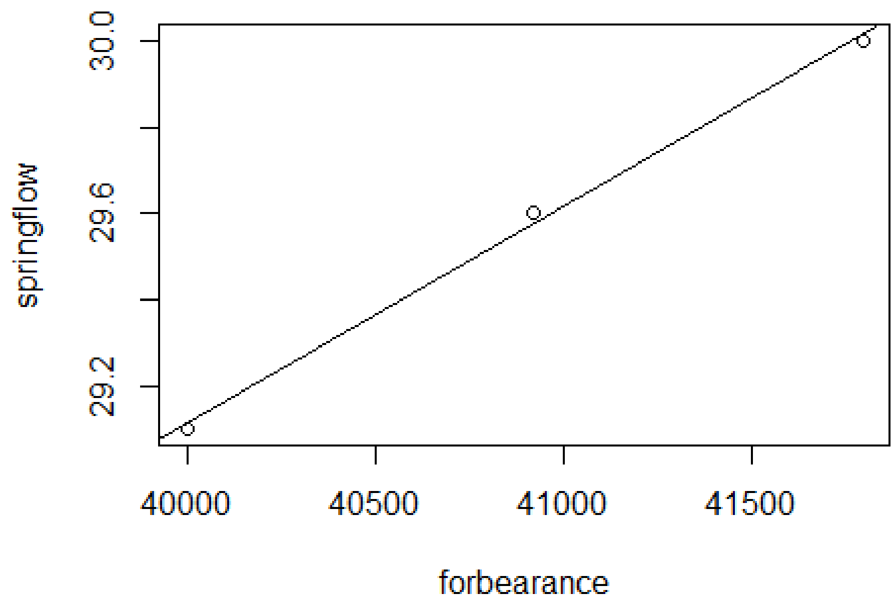

Figure 1 - What we are tempted by the limited data to see with default settings. Change looks big if the y-axis range is small.

So we have three different forbearances that produce three springflow forecasts. Forecast standard deviation is about 8 cfs, sample size is 3 so d.f.= 2. Replot with 90% CI.

```
plot(springflow~forbearance,ylim=c(0,60), xlim=c(39500,42000))
points(x=forbearance,y=springflow+qt(c(0.95),2)*(8/sqrt(2)),pch="?")
points(x=forbearance,y=springflow+qt(c(0.05),2)*(8/sqrt(2)),pch="?")
abline(lm(springflow~forbearance))
```

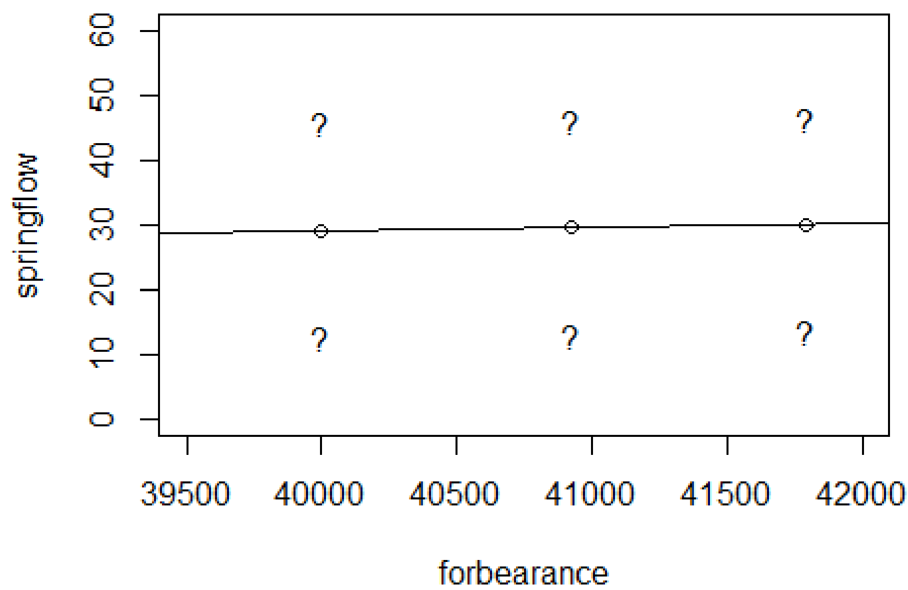

*Figure 2 - Now with the **90%** CI based on a t distribution with 2 d.f and se=8 cfs/. Last time I saw a table it seems the actual sd was higher than the 8 cfs used here. (Jim Winterle said "around ten" in the meeting March 27,2019.)*

Calculate the p(x <= 30|model 2). The probability p(x <= 30|model3)=0.5 because 30 is the center point of the forecast. Use these probabilities to form a ratio p(x <= 30|model3)/p(x <=30|model2). The calculations indicate only a small increase in the probability that mean spring flow during DOR is >= 30. Further, the actions under the third model will only lower the probability from 0.525 to 0.50.

```
pt((30-29.6)/(8/sqrt(2)),2)

## [1] 0.5249688

pt((30-29.6)/(8/sqrt(2)),2)/0.5

## [1] 1.049938
```

Maybe the error distribution of the EAA MODFLOW model is not a *t* distribution, as the quote above mentions a considerable bias. Maybe we shouldn't settle for a 50% probability of "success", but that's for another day.

Question

Regarding the work plan for MODFLOW in Liu et al., in which you plan to run the DOR model for each of the parameter realizations in the ensemble (i.e. if the ensemble has 500 members, this would require 500 model runs):

How many parameters per set in the ensemble? (Winterle:"perhaps a thousand?"") Well, 500 "samples" in 1000 dimensions isn't very many at all.

You use the terminology of a Bayesian analysis in the work plan, but subvert the spirit of the Bayesian approach. It's better to model each parameter independently. What EAA has described, though, is developing a sampling distribution for mean springflow resulting from DOR conditions, **given** (i.e, *conditional on*) the parameter sets in the ensemble. By modeling a "small" number of realizations of predetermined ensembles of parameters we severely limit the parameter space. Space is big. Further we loose the opportunity to learn about covariance matrix, and the correlation between parameters. Taking advantage of the correlation structure of the parameters lets the data do the talking while serving to confine the parameter space , a goal of using the ensembles , I suppose, since it shortens convergence times. Without a fully Bayesian approach, we have no idea of the likely distributions of each parameter, or indeed if the best set was in the ensemble.

The fully Bayesian approach

The fully Bayesian approach requires (perhaps vague) prior distributions on each model parameter, generating a parameters set from the parameter priors, forecast based on the priors chosen, observing the data and evaluating the likelihood of the parameters (collectively the model likelihood), given the data, and using the likelihood to update the prior distributions of the parameters to posterior (to the data observation) distributions. Posterior parameter distributions are then used as priors to select the second set of independent realizations of the parameters, and process of drawing parameters sets, forecasting with those sets, observing data and updating the parameter priors (using Bayes theorem). Repeat.

A Bayesian alternative to MODFLOW

It may be impractical to run the MODFLOW model enough times to have multiple MCMC chains converge, a problem that gets worse as the number of parameters increases. It is possible (Lamon, 2015) to take advantage of the relationship between flow and J-17 elevation to develop the desired sampling distribution for the mean springflow resulting from DOR conditions. Such a *probability network model* could be used with the DOR scenario inputs for this purpose.

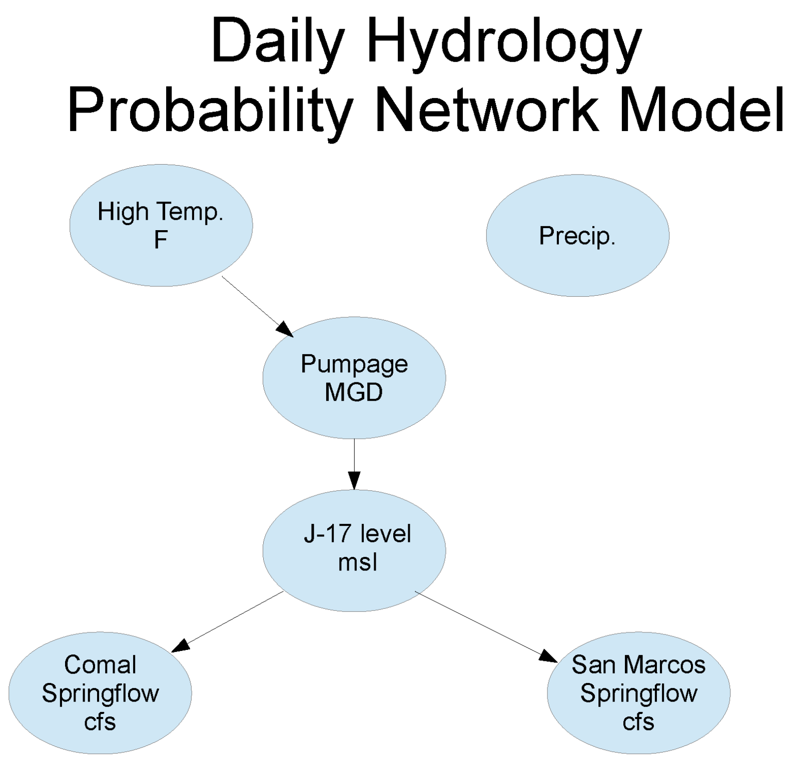

Figure 3 - The Daily Hydrology Probability Network Model of Lamon, 2015. Arrows represent Dynamic Linear Models the afferent node (predictor variable) to the efferent node (response variable). Daily maximum temperature predicts Pumpage, which predicts J-17 level, which then predicts the springflows. Ovals are "nodes", representing probability distributions, conditional on the variables afferent (opposite the arrow point), such that Spring flows are conditional on J-17 level, etc. The time step is daily.

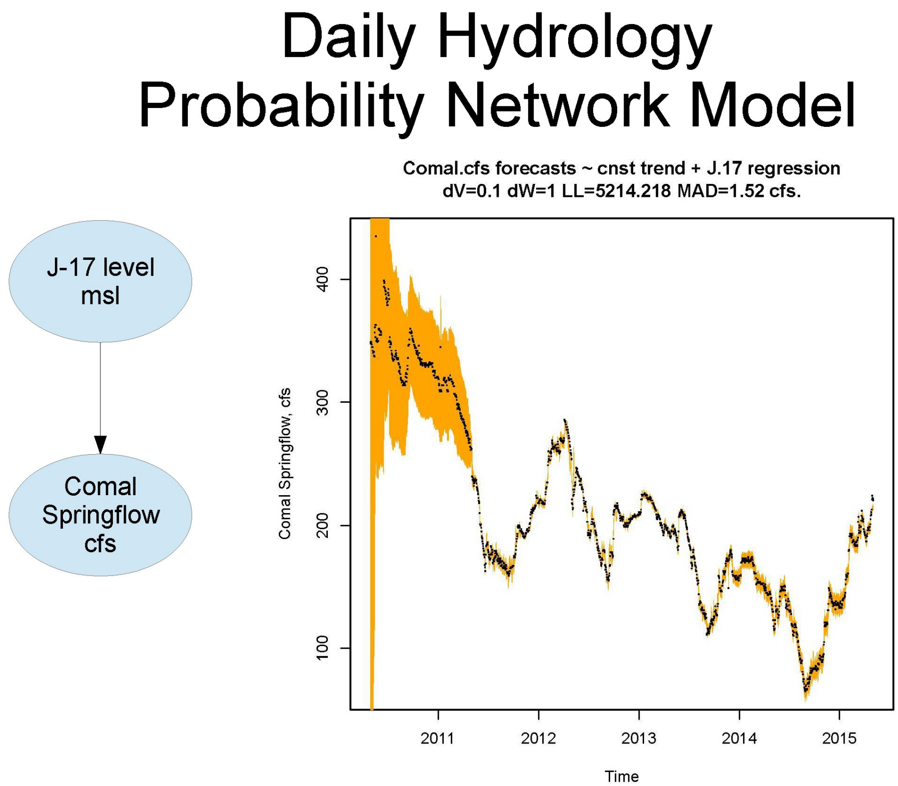

Figure 4 - Dynamic Linear Model predicting daily average Comal springflow as a function of a constant trend and daily average J-17 elevation predictor variable, from Lamon, 2015. This model has a median absolute deviation (MAD) of 1.52 cfs.

Statement

With millions in VISPO payments at stake riding on differences in forecast means of less than 1 cfs, and long term investments in modeling to develop those forecasts, it seems as if we'd be closer to a finished decision tool than a 30-40 cfs bias and 8 cfs mean squared error indicates. This is not meant as an argument against the changes to VISPO. Rather it is meant as an argument for investment in quantification and reduction of uncertainty in the springflow forecasts, and to offer my opinion on a logical course of action by which it may be achieved.

References

Lamon, EC, 2015. Daily Hydrology Probability Network Model, pdf.

Liu, A, N Troshanov, J Winterle, A Zhang, S Eason, 2017. Updates to the MODFLOW Groundwater Model of the San Antonio Segment of the Edwards Aquifer. Available at: https://data.edwardsaquifer.org/documents/2017_Liuetal_UpdatestotheMODFLOWGroundwaterModeloftheSanAntonioSegmentoftheEdwardsAquifer.pdf.

HDR, 2011. Evaluation of Water Management Programs and Alternatives for Springflow Protection of Endangered Species at Comal and San Marcos Springs. Available at: http://eahcp.org/wpcontent/uploads/2019/02/Appendix-K.pdf