Colorado River Risk Study Phase III Update

June 20, 2019

Modeling Assumptions, Additional Results, and other Background Information.

Disclaimer: The findings presented herein are for discussion purposes only, and do not represent the official position of any entity with respect to factual or legal matters concerning the Colorado River.

All Results Presented herein are Preliminary and Subject to Change

Preamble

The information herein is intended to accompany the handout of slides to be presented by John Carron of Hydros Consulting at the June 20, 2019 Four West Slope Basin Joint Roundtable Meeting in Grand Junction, Colorado. It provides additional background information and results related to the presentation, but is not intended to be a comprehensive report on the work, which will be produced as a Final Report this summer.

Please note that the presentation slides and this supplementary material is intended to provide background information regarding the hydrology, water operations, demands, and associated risk factors that may be considered when formulating future water management policies and strategies. They are not comprehensive in that regard (for example, we make no attempt to quantify the economic costs or benefits of any hypothetical actions), nor should they be taken in any way as a proposal for action or statement of policy by any participating group.

As will become readily apparent in the presentation, the results presented are inextricably tied to the assumptions made about future hydrology, the fate of the 2007 Interim Guidelines, the Drought Contingency Plan, the rate of future growth of demand in the Upper Basin and Colorado, and a number of other model assumption. We are not attempting to forecast the future.

This document is organized into two sections. The first provides a broad overview of the modeling assumptions, including hydrology, demands, river operations, water rights administration, and the generation of output statistics. The second section generally follows the slide presentation sequence, providing additional background information and/or anticipating questions that may arise from those particular slides.

Model Background

1. Modeling Tools

The results presented for Lake Powell and Lee Ferry flows are from model runs simulated using the Colorado River Simulation System (CRSS) see, for example, https://www.usbr.gov/lc/region/g4000/riverops/model-info-APR2018.html). The CRSS Model is available from Reclamation online: http://bor.colorado.edu/Public_web/CRSTMWG/CRSS. This model has been modified to reflect various components of the Drought Contingency Plan, Minute 323 of the U.S./Mexico Treaty, and to incorporate river flows at the various outflow points from the State of Colorado, which are generated using StateMod (see below, and also the final report from Phase II Task 2 of the Risk Study).

To simulate water use within the State of Colorado, we utilize the StateMod modeling tool available from the Colorado Water Conservation Board (CWCB) (https://www.colorado.gov/pacific/cdss/statemod). The StateMod versions used in this analysis included the "west-slope linked model" provided by the CWCB, and the individual basin models available through the CDSS website.

The linked model has the same basic model structure as used by the State for its Compact Compliance Study. The linked model as provided by the CWCB did NOT include any assumptions regarding methodologies for administering a compact call, nor did it include any alternate hydrology or demand data outside of what can be obtained from the CDSS website. We also employed the individual basin models for each west slope sub-basin. These are the "Yampa/White", "Colorado", "Gunnison", and "San Juan/Dolores" basins. The Yampa/White basin model is actually two separate model networks, and so results are presented separately for those two basins.

2. Model Assumptions

Hydrology:

The hydrologic basis for the modeling results herein is the so-called "Stress Test Hydrology" which covers the calendar years 1988-2015. The Stress Test hydrology was used extensively by Reclamation and the Upper Colorado River Commission when evaluating possible actions for the Drought Contingency Plan, and was also used in Phases I and II of this study.

None of the StateMod models used for this work extend through 2015. As a result, we appended data for the "missing" years by examining historical flows at gage locations for both the missing years and other available years in the model database. The missing years were then "filled" by using years that most closely replicated the gage volumes. This also allowed us to synchronize the StateMod model with the CRSS model, which already contained the full Stress Test period hydrology.

Water Rights Administration:

We use two different approaches to simulate water rights administration in StateMod. The default behavior in StateMod is to use the administration numbers assigned to each water right when simulating priority administration of each basin. A water right's administration number is generally based on its adjudication date, prior adjudication dates, and its appropriation date. Use of the administration numbers is StateMod is consistent with the generally accepted understanding of how rights are administered "on the ground".

The second approach is to use appropriation dates. When considering both the Colorado River Compact and potential administration across sub-basins within Colorado, it is worth considering differences in the timing of sub-basin adjudications, and also the interplay in timing between adjudication dates and the enactment of the Compact. It is also important to note that an appropriation date in and of itself does not guarantee a pre-compact right, as the use of that water may not have been perfected by the date of the Compact.

Unless otherwise noted, we use the administration number paradigm for the StateMod analyses in this study.

<u>Demands</u>:

Two different data sets were used to represent “current” and “future” demands. For StateMod, the baseline data set is the best estimate of current demands within Colorado. The purpose of the “future” demand data set was to illustrate how an increment of additional consumptive use could impact the level of risk in the upper basin. Through coordination with the west-slope BRT technical representatives, we developed a “reasonable increment” of growth for each basin. In basins with Programmatic Biological Opinions (PBOs), we based the increment of growth on assumed full use of the PBO “allowances”. For basins without PBOs, we developed additional demands that were subjectively similar in scope to those developed under the PBOs, and to the extent possible based on existing decrees, projects, or published studies and reports. These future demands were added to the StateMod model(s) and a new set of depletions and basin outflows were developed*.

The table below shows the new demands by basin in the right-hand column. The average yield of the new demands is shown in the left column of data, and the total increase in consumptive use by basin is shown in the center column. Note that introduction of new demands on the system does not necessarily translate into additional depletions of the same volume. In the Colorado and Southwest basins in particular, new demands may be limited due to hydrologic shortages, particularly in dry years. The average annual increase in consumptive use of Colorado River Basin water in Colorado resulting from the addition of ~384 Kaf of new demands was slightly less than 290 Kaf, or about 11.5% of the current average annual depletion.

The values developed for the hypothetical future use in Colorado needed to be replicated for the other states of the Upper Basin in order to run future scenarios in CRSS. Using Colorado’s current (2019) share of demands under the 2016 UCRC demand schedule we matched the 11.5% increase for Colorado with an upper-basin-wide increase of 11.5%. That increase in use is approximately equivalent to 2037 demands in CRSS (using the 2007 UCRC demand schedule). Thus, when running CRSS for future use projections, Wyoming, Utah, and New Mexico demands were based on the 2037 demand level, which is an increase over current demands of about 300 Kaf for those three states.

StateMod Linked Model	Future Use Depletions (AF/yr)		
	Average Yield of New Depletions	Average Increase in Basin Depletions	Input Demand
Yampa	29,506	29,485	30,104
White	61,839	61,787	65,000
Upper Colorado & Front Range	86,077	82,425	120,450
Gunnison	31,053	31,100	37,900
Southwest	81,104	82,355	130,499
StateWide	**289,578**	**287,153**	**383,953**

**Note: The "future" demands shown are NOT intended to advocate for any specific projects, to limit or push any specific level of development, or to suggest appropriate allocations of growth across sub-basins. The purpose of simulating these demands is primarily to develop an understanding of how increased consumptive use in the upper basin as a whole may impact the likelihood of reaching critical elevations at Lake Powell or critical volumes at Lee Ferry.*

<u>Trans-Mountain Diversions (TMDs):</u>

As much as 500 Kaf of water is diverted from the Colorado River Basin into other basins within the State of Colorado. These diversions can be found in most Colorado sub-basins. Well over 95% of TMD water is diverted from the mainstem of the Colorado River itself. An even higher percentage of the TMDs used for M&I water originate from the Colorado mainstem. For this study, we only examine Colorado mainstem TMDs and the impact of a potential compact call on those water users.

<u>CRSS River Operations</u>:

The CRSS model simulates operations of many of the large Federal storage projects within the basin. Within Colorado this includes the Aspinal Unit and Taylor Park Reservoir. The other major CRSP reservoirs are also simulated (Powell, Navajo, Flaming Gorge), as well as the large main stem reservoirs in the Lower Basin (Mead, Mohave, Havasu). Operating policies for the Upper Basin CRSP facilities are based primarily on the Records of Decision for each (including the 2007 Interim Guidelines that dictate Lake Powell operations), and are part of the "standard" ruleset for the CRSS model.

Drought Contingency Plans (DCPs) and Minute 323 of the US/Mexico Treaty: CRSS was modified to incorporate the major components of the recently approved DCPs and Treaty Minute 323. For the Upper Basin, we only include the proposed Drought Operations of the CRSP facilities in the model. The Drought Operations ruleset was developed jointly by the UCRC Engineering Committee and Reclamation during DCP negotiations. The final version used by Reclamation in its DCP modeling is included in our simulations. No attempt was made to incorporate demand management or cloud seeding/flow augmentation in our modeling.

For the Lower Basin DCP, the model reduces deliveries to the states as laid out in the Lower Basin DCP agreement, and includes an assumed annual contribution by Reclamation of 100 Kaf. Minute 323 is also represented in the model, and reductions in deliveries to Mexico through their pro-rata "matching" of both the Interim Guidelines shortages and the DCP reductions are included.

<u>Model Execution and the Index Sequential Method</u>:

The CRSS model uses the "Index Sequential Method" (ISM) to perform multiple simulations using a single hydrologic data set. In this study, the Stress Test hydrology spans the period 1988-2015. That 28 year period of data is used to develop 28 different hydrologic traces. Each of these traces is then modeled in CRSS. Each simulation (<u>trace</u>) starts with a different year. The first trace is 1988-2015. The second trace begins with year 1989, runs through 2015, then appends 1988 as the last year of the trace. The third trace begins in 1990, runs through 2015, and then appends 1988 and 1989 onto the end. In this fashion, each year of the stress test period is used once as the start year, and the traces "loop through" the historical period.

Slide Presentation Addenda

<u>Slide #3:</u>

The entire text of Principle 4 reads:

"***Principle 4: A collaborative program that protects against involuntary curtailment is needed for existing uses and some reasonable increment of future development in the Colorado River System, but it will not cover a new TMD.***

A collaborative program that protects existing uses and an increment of future development is a necessary element of Colorado's water planning, regardless of whether a new TMD is developed. The Framework includes this principle to make clear that a collaborative program would not protect a new TMD.

The collaborative program should provide a programmatic approach to managing Upper Division consumptive uses, thus avoiding a compact deficit and ensuring that system reservoir-storage remains above critical levels, such as the minimum storage level necessary to reliably produce hydroelectric power at Glen Canyon Dam (minimum power pool). A goal of the collaborative program is that protection of Colorado River system water users, projects, and flows would be voluntary and compensated, like a water bank. Such protection would NOT cover uses associated with a new TMD.

A second goal of the collaborative program is protection of the yield of the water supply systems in place in the Colorado River Basin from involuntary curtailment. To achieve this goal, the program would need to expand to accommodate future western slope growth and growth of existing water supply systems, the pace of which is not now known. Protecting additional consumptive uses will increase the program's scope and challenges. Some basins, such as the less-developed Southwest and Yampa/White/Green Basins, anticipate the need for future development and will seek terms to accommodate it in the collaborative program. Regardless of "when" a use develops, the program would strive to protect uses at the time of shortage, with the exception of a new TMD. By adapting to accommodate increased uses at any given time, the program should not lead to a rush to develop water rights. Section 9.1 of Colorado's Water Plan provides additional discussion of the collaborative program.

The collaborative program will develop in concert with intra- and interstate water policies. The IBCC and roundtables can provide an important forum for sharing the work of ongoing interstate negotiations, scoping technical analyses, and identifying issues of concern at the stakeholder level, as well as providing input to the CWCB as it manages and conducts the technical, legal, economic, and other studies necessary for implementation.

<u>Slide #4:</u>

Why elevation 3,525'? Section II.A.2 of the AGREEMENT FOR DROUGHT RESPONSE OPERATIONS AT THE INITIAL UNITS OF THE COLORADO RIVER STORAGE PROJECT ACT on the rationale for using 3525' as the Lake Powell target elevation:

Target Elevation: For purposes of this Drought Response Operations Agreement only, Lake Powell surface elevation 3,525 feet mean sea level ("msl") will be considered the "Target Elevation" for minimizing the *risk of Lake Powell declining below minimum power pool (approximately elevation 3,490 feet msl) and to assist in maintaining Upper Division compliance with the Colorado River Compact. The Parties agree that this elevation appropriately balances the need to protect infrastructure, compact obligations, and operations at Glen Canyon Dam, as storage approaches minimum power pool with the Upper Division States' rights to put Colorado River System water to beneficial use.*

Elevation 3,525 is also the threshold for the Lower Elevation Balancing Tier of operations under the 2007 Interim Guidelines:

Lake Powell Operational Tiers (subject to April adjustments or mid-year review modifications)		
Lake Powell Elevation (feet)	**Lake Powell Operational Tier**	**Lake Powell Active Storage** (maf)
3,700		**24.32**
	Equalization Tier equalize, avoid spills or release 8.23 maf	
3,636 – 3,666		**15.54 – 19.29**
(see table below)	**Upper Elevation Balancing Tier** release 8.23 maf; if Lake Mead < 1,075 feet, balance contents with a min/max release of 7.0 and 9.0 maf	(2008 – 2026)
3,575		**9.52**
	Mid-Elevation Release Tier release 7.48 maf; if Lake Mead < 1,025 feet, release 8.23 maf	
3,525		**5.93**
	Lower Elevation Balancing Tier balance contents with a min/max release of 7.0 and 9.5 maf	
3,370		**0**

(Record of Decision – Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead, p.50.)

Note that releases under the Lower Elevation Balancing Tier could be as large as 9.5 Maf, while the maximum release in the Mid-Elevation Release Tier is 8.23 Maf.

<u>Slide #5:</u>

The May 2019 24-Month Study from Reclamation (https://www.usbr.gov/lc/region/g4000/24mo.pdf) forecasts that Lake Powell will end 2019 with 12,368,000 acre-feet of storage. That number is developed from the Colorado Basin River Forecast Center's most probable inflow data for the remainder of 2019 and projected releases, evaporation, and changes in bank storage through December 31.

Slide #6:

The “Stress Test Period” covers the calendar years 1988-2015. The average naturalized flow during that period is 13.18 Maf, with a maximum annual natural flow of 20.3 Maf in 2011, and a minimum of just over 6.0 Maf in 2002.

The average annual flow over the period of record (1906 – 2018 provisional) is 14.75 Maf.

The average annual flow over the period 2000 – 2004 is 9.55 Maf.

The average annual flow over the period 2000 – 2018 (provisional) is 12.36 Maf.

(Statistics above derived from data provided by Jim Prairie, Upper Colorado Region, Reclamation; May 3, 2019)

All of the modeling results presented herein are based on simulations using the Stress Test period hydrology. For this work we did not consider paleo-hydrology or climate change forecasts.

Slide #7:

For an overview of the modeling tools and assumptions used in this analysis, refer to the ***Model Background*** section above.

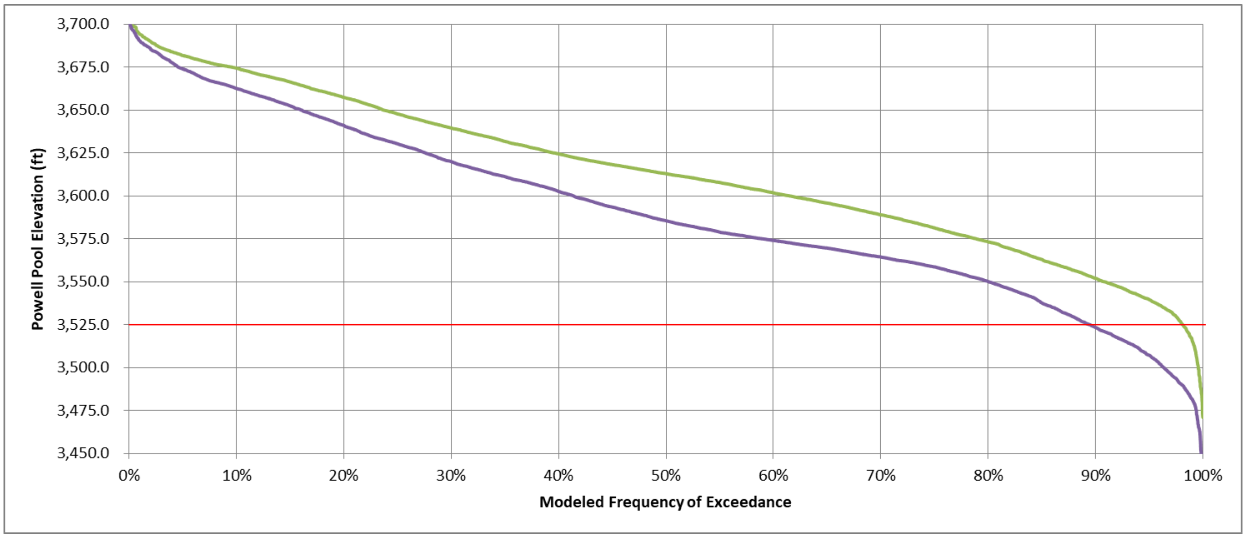
Background on the statistics presented in bullets 1-3: Recall that using the ISM method, the model generates a total of 28 traces, resulting in 28 simulations. For this study, we perform statistical analysis on the first 25 years of each simulation. Thus for the “current conditions” run there are a total of 28 traces x 25 years per trace = 700 years of data. There are two main statistical approaches we use to evaluate the outputs.

One is to quantify the likelihood that a specific event happens in any year across all the traces. Using Lake Powell Elevation as an example, we might count the number of years that Lake Powell drops below 3525 on January 1. If we find 11 such occurrences, then the likelihood of Lake Powell hitting that elevation in any given year would be 11/700 = 1.43%.

The second approach is to quantify the number of traces in which a particular event occurs. Keeping in mind that each trace is a hypothetical projection into the future, we would want to understand how many of those possible futures contain a bad outcome. It may not necessarily matter if it happens next year or in 20 years, we just want to know IF it happens. Now let’s assume that each of those 11 events mentioned above happened in different traces (our “futures”). Of all our assumed futures, 11/28 or ~39% are likely to encounter this condition at some point in the next 25 years. Now the risk looks very different, even though it is based on the same data.

This second approach, looking across the possible futures, is the method we use to generate the statistics for Slide #7.

The following exceedance curve uses the first approach, and the same model outputs for current and future demand runs as used for Slide 7. The difference between these two statistical methods explains why the exceedance curve - showing modeled likelihood across <u>all years</u> - can be perceived to represent a very low risk.



Slide #8:

Hopefully the previous presentation on the DCP provided sufficient background on this slide.

Slide #9:

The definition of a compact deficit itself is far from settled, and we are not going to delve into that question here. Nor is it a foregone conclusion that a deficit, if and when it does occur, would result in an involuntary curtailment.

Slide #10:

The data in this slide is developed from the individual CDSS (StateMod) basin models. The models use the current conditions (baseline) demand set from the CDSS website. These depletion values include evaporation and other losses incidental to water use. The variability in consumptive use is a result of hydrologic variability and the resulting simulation of junior users being called out in the model. For this and most subsequent slides, the main stem Colorado depletion values will be presented as a whole, as well as split into in-basin and trans-mountain diversion (TMD) uses.

Slides #11 - 12:

The questions surrounding the definition of pre-compact vs post-compact water rights (and perfected use) are numerous and beyond the scope of this work. Slide 12 shows the differences between the 1922 and 1929 compact dates, when determining pre-compact water use in Colorado. The default behavior for StateMod is to use Administration Numbers – which are derived largely from adjudication dates – when simulating water allocation. StateMod can also use appropriation dates to simulate the administration of water. Using appropriation dates instead of administration numbers when modeling a compact call yields between 105 Kaf and 125 Kaf additional pre-compact consumptive use in Colorado, depending on the assumption of compact date of enforcement. The results in this presentation related to a full compact call are based on model simulations that use administration numbers, and the Nov 24, 1922 compact date.

Slide #13:

To simulate the effects of a compact call on all post-compact rights, and to determine the total amount of (modeled) pre-compact consumptive use, we apply an infinitely large demand at the bottom (state line) of each model, with a priority date of 11/24/1922. Because there could be significant inter-annual variability in yield based on hydrology, we simulate the call for the entire simulation period, and then compute the average consumptive use across all years. This average pre-compact consumptive use totals ~1.6 Maf, and is shown in the middle column. The first column is from slide 10, and the third column is simply the percent of each basin' consumptive use that is attributable to pre-compact rights.

Slide #14:

The average annual volume of post-compact consumptive use is computed by subtracting the pre-compact average from the total average for all users. This difference represents approximately 932 Kaf of consumptive use by post-compact rights. The table percentages show the distribution by basin of those post-compact rights relative to the total, and the pie-chart is a visual representation of those percentages.

Slides #15-#26:

The results in this group of slides are based on a number of different "what-if" scenarios. The purpose of these scenarios is NOT to advocate for a particular approach to involuntary curtailment, nor to exclude any other possible approaches.

Slide #15:

What if…

Perhaps a total curtailment of all post-compact rights is not necessary to overcome a compact deficit, or perhaps an agreement is reached whereby Colorado water users must curtail a certain amount of consumptive use over some period of time. One obvious question would be, "*how deep would a call across all basins using a single administration number need to be in order to yield a certain volume of reduced consumptive use*"? To answer this question, we turned to the linked StateMod model that combines all the west-slope basin models into a single model that can be used to simulate the impact of a single call on all Colorado River water users.

To estimate the administration dates in the table, we place a large "demand" at the outflow point of the linked model, and iterate the model at different administration dates until we achieve the desired average yield. So for example, on average, to achieve a statewide reduction of 300,000 af. would require curtailment of all rights junior to September 1940.

To reiterate: all these simulations use administration numbers (based largely on adjudication dates), not appropriation dates, when simulating calls. The difference between depth of call when simulating these volumes using those two different administrative schemes is very small.

Slide #16:

This slide simply takes the total volumes and call dates computed in the previous slide, and breaks out how much reduction in consumptive use would result in each of the sub-basins. For example, a state-wide September 1940 call would result in curtailment of an average of 40,233 af. in the San Juan/Dolores (Southwest) basin, or about 13% of the 300,000 af. total.

Slide #17:

This graphic is simply a bar chart reproduction of the data from the previous slide. The lighter colored "In-Basin" and "TMD" bars are the breakout of the Colorado mainstem total into those two constituent user types.

Slide #18:

In Slides #15-#17, we explored what a partial call across all basins using a single administration number might look like. Another approach might be to allocate the volume of required consumptive use reduction pro-rata, across the sub-basins, based on each sub-basin's percentage of *post-compact* use. We can also explore the split in post-compact use between in-basin and TMD use in the Colorado mainstem.

Slide #19:

To develop a pro-rata distribution of each sub-basin's hypothetical obligation to meeting the state-wide total reduction, we apply the percentage of post-compact use by sub-basin that was shown in slide #14, and compute each sub-basin's portion. The volumetric requirements under this hypothetical approach are shown in the table.

Slide #20:

Under the scenario described in the previous slide, each sub-basin is responsible for its own pro-rata reduction in post-compact depletions. There are a number of different ways those sub-basins could agree on to reduce that volume of use. One such approach would be to implement a call within that sub-basin to a seniority that would yield the required volume.

For example, if the State is required to conserve 300,000 af, the Yampa basin's portion of that volume under this approach would be 18,811 af. Using the Yampa StateMod model, we can compute a call date of August 1962 that would yield, on average, that volume of reduced consumptive use.

Slide #21:

We again perform a set of runs in StateMod using each sub-basin model to determine the call seniority by sub-basin that would be required to generate the target volumes. Those dates and associated volumes are shown in the table.

Note that a comparison can be made for each basin, by date and volume, with the state-wide call date shown in slide #15.

Slide #22:

Another hypothetical we can explore is allocating responsibility on the Colorado mainstem between in-basin post-compact uses and TMD post-compact uses (The vast majority of TMD consumptive use is post-compact). We only perform this analysis on the Colorado mainstem, as TMDs from other sub-basins are a very small percentage of total water use in those basins.

The Colorado mainstem as a whole consumes 67.2% of post-compact water in the State. That 67.2 percent is split into 57.1% (of the state-wide total) for the TMDs, and 10.1 % of the state-wide total for in-basin Colorado mainstem users.

As a percent of the Colorado mainstem alone, TMDs constitute 85% of post-compact use, with in-basin use comprising the remaining 15%.

Note that the call seniority is largely unchanged for the TMDs, but the in-basin call seniority is somewhat relaxed by this approach.

Slide #23:

From the above analyses, we can compare a state-wide call with a pro-rata distribution based on post-compact use, and see which sub-basins would experience deeper or shallower calls and associated volumes of use reduction.

Again, these call dates are the seniority required *on average* to yield the target volumes.

Slides #24-#26:

This set of slides aggregates the previous data into a comparison of these partial curtailment approaches and presents them by volume, and across each sub-basin. Note that the lighter shaded bars represent the breakout of Colorado mainstem uses into in-basin and TMD components.

Slide #27:

This is a short and necessarily incomplete summary of observations. These observations are not intended to be comprehensive, but to be a launching point for additional conversation.