Improving Binational Water Management Policy through Science

Edward Drusina, Suzanne Tillery, Adrian Cortez, and William Finn

In the North American Southwest, water is a vital but disappearing resource. Water management officials along the United States/Mexico border are using binational water management policies that are over 100 years old. As the hydrology of the region changes, this paper examines new approaches using science and technology in the allocation of the Rio Grande Basin water to meet the current and future water needs of the two countries. The IBWC, along with its respective stakeholders, will continue with the vision of developing a binational cooperative basin management plan to safeguard the interests on both sides of the border.

1 Introduction

Water is a vital resource in the southwest of the United States (U.S.) and the northeast of Mexico. Increasing population and irrigation demands along the international border of the Rio Grande (known as the Rio Bravo in Mexico), are putting a strain on an already sparse resource. (Note that *Rio* is the Spanish word for *River* and is used to refer to all rivers in this paper.) In order to more efficiently manage water use in this region, new approaches using science and technology are required to better allocate water to the two countries.

The U.S. and Mexico share the waters of the Rio Grande that flow from, Fort Quitman, Texas, to the Gulf of Mexico. The water is shared in accordance with the *U.S. – Mexico 1944 Water Treaty for the Utilization of Water of the Colorado and Tijuana Rivers and of the Rio Grande* (Treaty series 994, 1946). This treaty is referred to in this paper as *1944 Water Treaty*.

1.1 Treaty Summary

In accordance with Article 4 of the *1944 Water Treaty*, one-third of the flow reaching the Rio Grande from six (6) named-tributaries in Mexico is allotted to the U.S., while the other two-thirds are allotted to Mexico. Over a five-year period, the one-third delivered to the U.S. "…shall not be less, as an average amount in cycles of five consecutive years, than 350,000 acre-feet (431,721,000 cubic meters) annually…" except in "…the event of extraordinary drought or serious accident to the hydraulic systems on the measured Mexican tributaries…". Should there be any deficiencies in deliveries, they must be made up during the next five-year cycle. Over the five-year period, a minimum of 2,158,605,000 cubic meters (1,750,000 acre-feet) should be delivered to the U.S. A five-year cycle is ended early whenever the conservation capacities assigned to the U.S. in the two International Reservoirs, Amistad and Falcon, are filled with waters belonging to the U.S.

The six (6) named-tributaries identified in the *1944 Water Treaty* are:

- Rio Conchos
- Arroyo de las Vacas
- Rio San Diego
- Rio San Rodrigo
- Rio Escondido
- Rio Salado

In addition to these six tributaries, the *1944 Water Treaty* lists various other tributaries that are allotted 100% to the country where the tributary originates.

In the past, there have been five-year cycles in which the delivery of water to the U.S. from the six named-tributaries has fallen short of the 431,721 thousand cubic meters (TCM) annual average target delivery rate described by the treaty. The four most recent five-year cycles that ended in deficit occurred during the cycle periods of 1992 through 1997, 1997 through 2002, 2002 through 2007, and 2010 through 2015. By not meeting this obligation, various measures have been taken in order to satisfy the five-year cycle deficits. Recognizing the measures taken to satisfy previous debts and present hydrologic conditions, more proactive options and measures are being analyzed to meet the obligations of the *1944 Water Treaty* and ensure that the U.S. receives any and all water allotted to it in a timely and predictable manner.

A RiverWare™ model was developed based on the requirements as defined by the *1944 Water Treaty* to explore new and innovative delivery options that maintain the spirit of the treaty while ensuring compliance and continued availability of water to upstream users. Adjustments are assigned to the model as a means of analyzing various delivery options. To analyze these adjustments, each option is easily modified in order to investigate various combinations of adjustments, and varying timeframes for their implementation. The results of these adjustments is presented clearly to evaluate the advantages and consequences of the actions taken. This RiverWare™ model is intended to be implemented as a joint binational model, for use by both the U.S. and Mexican Sections of the International Boundary and Water Commission (IBWC).

In accordance with the *1944 Water Treaty*, the IBWC is charged with applying the treaty and settling any differences arising in its application. Comprised of a U.S. Section and Mexican Section, each a part of its respective federal government, the two Sections are considered an international organization when they carry out joint projects.

2 Study Area

The six named-tributaries are allocated downstream from Presidio, Texas-Ojinaga, Chihuahua. Therefore, the area specified for this modeling effort is from the Rio Grande near Presidio, Texas-Ojinaga, Chihuahua, to the Gulf of Mexico, near Brownsville, Texas-Matamoros, Tamaulipas (Figure 1). The tributaries on the Mexican side of the Rio Grande are collectively known as the *six named-tributaries*, which are circled in red in the figure. There are multiple dams in Mexico that control releases to the Rio Grande, as indicated by the green triangle shapes in the figure. Along the Rio Grande, there are two International Reservoirs that straddle the border between the U.S. and Mexico: Amistad Reservoir and Falcon Reservoir, as indicated by the blue triangle shapes.

3 Treaty Summary

3.1 Treaty Area Components

Major hydrologic components are included in this study in order to analyze the effects of the options being assessed by the model. These components include major reservoirs in Mexico capable of contributing additional flows to the main channel of the Rio Grande. Other reservoirs exist within Mexico that are not included in the model, but which can be added as necessary to meet modeling objectives.

3.1.1 Major Dams on the Six Named-Tributaries

The major dams on the six named-tributaries are:

- Luis L. León (on Rio Conchos), with upstream dams of:
    - Francisco I. Madero, and
    - La Boquilla
- Centenario (on Rio San Diego)
- San Miguel (on Rio San Diego)
- La Fragua (on Rio San Rodrigo), and
- Venustiano Carranza (on Rio Salado)

3.1.2 International Reservoirs

The International Reservoirs located on the Rio Grande are Amistad Reservoir and Falcon Reservoir.

3.1.3 Other Mexican Tributaries

The tributaries below Falcon Reservoir that are identified in the *1944 Water Treaty* and normally allotted 100% to Mexico are Rio Alamo and Rio San Juan.

3.1.4 Major Dams on the Rio Alamo and Rio San Juan Tributaries

The major dams controlling flow on Rio Alamo and Rio San Juan are:

- Las Blancas (on Rio Alamo)
- Marte R. Gómez (on Rio San Juan), with upstream dam of:
    - El Cuchillo

4 Fundamental Concepts

There are some fundamental concepts and terminology employed by the model that need to be understood in order to use the model and evaluate the results. A brief discussion of these concepts and terminology is presented in the following sections.

4.1 Delivery

Delivery is a term used to identify water provided by Mexico to the U.S. to meet the five-year cycle treaty obligation. Under the treaty definition, one-third of the flow from the six named-tributaries is considered the delivery from Mexico to the U.S. Treating any other water from Mexico to the U.S. as a *Delivery* requires agreement between the U.S. and Mexican Sections of the IBWC.

4.2 Adjustments

An *Adjustment* is a volume of water delivered from Mexico to the U.S. outside of the normal delivery methods described in the *1944 Water Treaty*. This amount of water is added to the normal delivery in an attempt to meet the five-year treaty obligation.

4.3 Adjustment Types

Multiple *Adjustment Types* are identified in the model as options for delivering additional water from Mexico to the U.S. One example of an *Adjustment Type* would be to deliver more than one-third of the flow in the six named-tributaries to the U.S. Another example *Adjustment Type* would be to deliver an extra amount of water from one or more of the Mexican reservoirs.

The normal basis for making delivery adjustments in the model is to specify a percent range for each adjustment type, and compare the previous month percent of the delivery to see if it falls in that range. If it does, then a delivery adjustment for the specified adjustment-types will be attempted. All of the *Adjustment Types* considered by the model are described in subsequent sections.

4.4 Accumulated Delivery Target

The model uses a predefined, monthly "*Accumulated Delivery Target*" to determine if the actual deliveries are current or not. One of two (2) delivery target-lines must be selected by the user: either a constant delivery target-line, that starts at zero and continues in a straight line to the five-year cycle treaty value of 2,158,605 TCM; or a seasonal target line that starts at zero, but each year varies in a manner consistent with seasonal variations in deliveries. A graph of the accumulated delivery target lines is shown in Figure 2. An optional "*Accumulated Delivery Target*" may be selected which uses one of the "*Naturalized Inflow*" statistical levels for the delivery target, as described in the following sections.

4.4.1 Naturalized Inflow

The model provides an option to use naturalized (virgin) inflow as the basis for making adjustments to deliveries, instead of basing adjustments on measured flows on the six named-tributaries. This option is considered since at the time of the *1944 Water Treaty*, there were fewer dams on the Mexican tributaries and the allocation of water between the two countries considered the basin inflow in a more pristine state.

The idea is to use one of the naturalized inflow statistical levels as the target delivery value instead of the normal constant or seasonal target delivery line. The statistical levels are described in the following sections.

4.4.1.1.1 U.S. Percent Allocation of Naturalized Flow

Calculations were made using historical time-series data for flow in each of the six named-tributaries, and for the combined total of these tributaries, to determine the fraction of U.S. delivery (one-third observed flow) relative to the naturalized flow. The form of the calculation is:

$$U.S. Fraction\ of\ Naturalized\ Flow = \frac{U.S. Delivery\ Volume}{Naturalized\ Flow\ Volume} \quad (1)$$

Once time-series of this data for the named tributaries have been calculated, statistics for each time-series of the U.S. fractions of naturalized flow are computed at two (2) levels:

- MEDIAN – 50% of the data lies below this point
- SEMI-WET or Q3 (third quartile) – 75% of the data lies below this point

These statistical fractions are used in the model to create U.S. naturalized flow data sets by multiplying the naturalized flow value times the statistics fractions at each month:

U.S. Share of Tributary at MEDIAN level = Trib Naturalized Flow x MEDIAN level statistic (2)

U.S. Share of Tributary at SEMI-WET level = Trib Naturalized Flow x SEMI-WET level statistic (3)

This results in complete sets of naturalized inflow data for these statistical levels for each of the six named-tributaries and for the combined total of all tributaries.

4.4.1.1.2 Naturalized Inflow Target Volume

When naturalized inflow is used for the target volume, the model will make adjustments to deliveries in order to meet a user-specified statistic of the total naturalized inflow, either the median level (50%), or the Q3 level (75%). The total naturalized inflow is calculated as the sum of the statistics level volumes of each of the named-tributaries. For example, for the Q3 statistics level, the total naturalized inflow is calculated as:

$$\begin{aligned} TotNatFlow_{Q3} \\ = RioConchos_{Q3} + ArroyoVacas_{Q3} + RioSanDiego_{Q3} \\ + RioSanRodrigo_{Q3} + RioEscondido_{Q3} + RioSalado_{Q3} \end{aligned} \quad (4)$$

Where

$TotNatFlow_{Q3}$	= *total naturalized inflow at the Q3 level (MCM)*
$RioConchos_{Q3}$	= *Rio Conchos naturalized inflow at the Q3 level (MCM)*
$ArroyoVacas_{Q3}$	= *Arroyo de las Vacas naturalized inflow at the Q3 level (MCM)*
$RioSanDiego_{Q3}$	= *Rio San Diego naturalized inflow at the Q3 level (MCM)*
$RioSanRodrigo_{Q3}$	= *Rio San Rodrigo naturalized inflow at the Q3 level (MCM)*
$RioEscondido_{Q3}$	= *Rio Escondido naturalized inflow at the Q3 level (MCM)*
$RioSalado_{Q3}$	= *Rio Salado naturalized inflow at the Q3 level (MCM)*

The total naturalized inflow values are accumulated over the five-year cycle for use in calculating the naturalized flow deficit. Continuing with the example for the Q3 statistics level, the accumulated naturalized inflow is:

$$Accum\_TotNatFlow_{Q3} = \sum_{i=0}^{t-1} TotNatFlow_{Q3\_i} \quad (5)$$

The naturalized flow deficit is calculated from the accumulated total naturalized flow at the designated statistics level minus the accumulated named-tributary delivery. For the Q3 statistics level, this equation is:

$$NatFlowDeficit_{Q3} = Accum\_TotNatFlow_{Q3} - Accum\_NamedTribDel_{Q3} \quad (6)$$

The target volume for the adjustments each month is calculated as the naturalized flow deficit minus the accumulated adjustments at the previous time-step:

$$AdjTarget_{Q3\_t} = NatFlowDeficit_{Q3\_t-1} - Accum\_Adjustments_{t-1} \quad (7)$$

4.5 Hydrologic Conditions at the Six Named-Tributaries

The *Hydrologic Conditions* at the six named-tributaries are based on measured flows on these tributaries before they enter the Rio Grande River. This data is divided into quartiles where the first quartile is the volume below which lies 25 percent of the bottom data; the second quartile (median) divides the range in the middle and has 50 percent of the data below it; the third quartile has 75% of the data below it and the top 25% of the data above it. Two additional points are added to represent the lowest and highest regions of flow, with the lowest at a volume below which lies 2% of the bottom data; and the highest at a volume below which lies 98% of the data. For modeling purposes, each of these ranges are assigned a category by the IBWC:

- DRY condition is assigned to the 2% level
- SEMI-DRY condition is assigned to the 25% level
- MEDIAN condition is assigned to the 50% level
- SEMI-WET condition is assigned to the 75% level
- WET condition is assigned to the 98% level

These statistics are calculated individually for each of the named-tributaries, and for the combined total of all six tributaries. The model uses these statistics each month to determine which level the monthly flow values are in. For example, if the current month flow is greater than the 2% level volume, and less than the 25% level volume, it would be assigned to the SEMI-DRY condition. The user specifies under which *Hydrologic Condition(s)* adjustments may be made; for example, adjustment may only be made when the current flow is in the SEMI-WET or WET hydrologic condition.

4.6 Adjustment-Types

The model incorporates many alternate sources of water that Mexico may use to meet the *1944 Water Treaty* requirements. Inclusion of these *Adjustment-Types* is for modeling purposes only and does not imply that these modeled adjustments have been determined to be appropriate in light of the requirements of the *1944 Water Treaty* or other international agreements nor does it imply that these adjustments have been agreed to by the U.S. and Mexico. The *Adjustment-Types* are described in the following sections.

4.6.1 Additional Water from Mexican Reservoirs

When the storage volume in a Mexican reservoir is at a user-specified percent of its conservation level, deliver a user-designated volume of water.

4.6.2 Rio Alamo and Rio San Juan Water

Typically, Mexico receives 100% of the flow from the Rio Alamo and the Rio San Juan, which are located below Falcon Reservoir (as shown in Figure 1). The adjustment option for these tributaries, based on article 9(e) of the *1944 Water Treaty*, provides for some percentage of this flow to be delivered to the U.S. from Rio Alamo when Las Blancas storage is above its conservation level, or from Rio San Juan when Marte R. Gómez storage is above its conservation level. However, this delivery is contingent on Texas Commission on Environmental Quality (TCEQ), the primary stakeholder in Texas, being able to use and accepting the water delivered. In the model, the conditions assumed for TCEQ to be able to use the water are:

- Releases from Falcon reservoir must be greater than a user-specified flow value, and

XVI World Water Congress
International Water Resources Association (IWRA)
Cancun, Quintana Roo. Mexico. 29 May- 3 June, 2017

- Delivery value from Rio Alamo and Rio San Juan cannot be greater than the demands downstream of Anzalduas Dam, which is an international diversion dam on the Rio Grande downstream from Rio Alamo and Rio San Juan. These demands indicate the amount of water requested for use below Anzalduas.

The U.S. and Mexico would agree to credit deliveries from this source to Mexico's five-year cycle obligation.

4.6.3 Increase U.S. Share of Water from Six Named-Tributaries

In accordance with the *1944 Water Treaty*, the U.S. receives one-third of the flow in the six named-tributaries. Increase the delivered water to the U.S. from Mexico's two-thirds share of the six treaty tributaries when the U.S. agrees to accept such water and can put it to beneficial use. The U.S. and Mexico would agree to credit deliveries from this source to Mexico's five-year cycle obligation.

4.6.4 Increase Share of Unmeasured Tributary Flow

Normally, positive unmeasured tributary inflow is split 50/50 between the U.S. and Mexico. Provide a portion of Mexico's share of this unmeasured tributary flows to the U.S. The U.S. and Mexico would agree to credit deliveries from this source to Mexico's five-year cycle obligation.

4.6.5 Transfer of Storage in International Reservoirs

For this adjustment, ownership of storage may be transferred from Mexico to the U.S. in the International Reservoirs, Amistad and/or Falcon. The user specifies the percent of the deficit to transfer in Amistad, and the percent of the deficit to transfer in Falcon. The sum of these two percentages does not have to equal to 100. Both percentages may be set to 100, which indicates first Amistad will attempt to meet the entire deficit by reservoir transfer. If there is not enough water in Mexican storage to meet the deficit, then the remainder of the deficit will try to be met by transfer in Falcon.

4.6.6 Water above Conservation Level in Mexican Reservoirs

Delivery of water in user-specified Mexican reservoirs that are above the reservoir's conservation level.

4.6.7 Mexican Return Flow

Normally, all of Mexico's municipal return flows and irrigation drain return flows belong to Mexico. This may be adjusted to allow Mexico to give some percent of its return flow to the U.S.

4.6.8 Mexican Spring Inflow

Normally, Mexico is assigned 23.25% of the spring inflow at Amistad Reservoir. This inflow is from the many springs that were submerged when Amistad Reservoir was filled. This may be adjusted to allow Mexico to give some percent of its 23.25% share to the U.S.

5 Methodology

A RiverWare™ model was developed to represent the area from the Rio Grande near Presidio, Texas-Ojinaga, Chihuahua, to the Gulf of Mexico on a monthly basis to evaluate alternate sources of water that Mexico could deliver to the U.S. in order to meet the minimum annual average volume of water identified in the *1944 Water Treaty*. Each of the relevant hydrologic items in this region are included in the model, plus a number of options that may be employed to modify the amount of water delivered from Mexico to the U.S. The resulting effects of these options on the Mexican reservoir system and the International Reservoirs, Amistad and Falcon, are provided in order to evaluate the effectiveness of the various options. Mexico and the U.S. must agree on deliveries for any sources other than the treaty-specified one-third of the six named-tributaries. The RiverWare™ simulation model layout contains the workspace objects describing the system, along with multiple data objects, as shown in Figure 3. The *Accounting* option of RiverWare™ was used to distinguish the different types of water and the ownership of the water.

6 Case Studies

A variety of scenarios were simulated with the RiverWare™ model on historic five-year cycles that ended in a deficit (i.e. did not meet the treaty required target) to consider the effects of adjustments on both the change in delivery volume and changes in the Mexican reservoirs.

Several scenarios were analyzed to compare the differences between using the seasonal delivery target line, and using the two naturalized inflow statistics levels for the delivery target. The adjustments-types that were applied to all three scenarios are shown in Table 1. The delivery targets and general results from these scenarios using two five-year cycles from 2010 to 2020, are described below.

6.1 Scenario 1 – Seasonal Delivery Target

For the first scenario, the seasonal target line was used for the delivery target, and adjustments to the six named-tributaries were made when the U.S. share of flow in the six-named tributaries is less than or equal to the MEDIAN, SEMI-WET or WET historical, statistical levels.

At the time of the model run, which was near the end of the first cycle, there was a deficit as seen in the accumulated delivery plot of Figure 4. This deficit was eliminated in the model by the adjustments described in Table 1. For this scenario, it was also projected that the second five-year cycle would end in a deficit without the adjustments applied at the beginning of 2020.

6.2 Scenario 2 – Naturalized Inflow Target at the 50% Level

The second scenario makes adjustments for the six named-tributaries to try to match the median (50%) level of the U.S. allotment of naturalized flow instead of trying to meet the seasonal target delivery line.

For this scenario, no adjustments ended up being made in either of the two-cycles, as shown in Figure 5. At this point we could tell that the settings would not provide enough water to meet the delivery targets and evaluating this simulation was not continued.

6.3 Scenario 3 – Naturalized Inflow Target at the 75% Level

The third scenario makes adjustments for the six named-tributaries to try to match the Q3 (75%) level of the U.S. allotment of naturalized flow instead of trying to meet the seasonal target delivery line.

The results from this scenario are similar to the results for Scenario 1. At the time of the model run, which was near the end of the first cycle, there was a deficit as seen in the accumulated delivery plot of Figure 6. This deficit was eliminated by the adjustments described in Table 1. However, for this scenario, even though a deficit is projected in the second five-year cycle, the deliveries with adjustments more closely follow the naturalized-inflow delivery target line than in Scenario 1.

7 Results and Discussion

Scenarios 1 and 3 both met the end-of-cycle delivery targets, however, Scenario 3 met the target with deliveries closer to the seasonal target line throughout the cycle, so the results from this scenario will be further explored.

7.1 Accumulated Adjustments by Type

Comparing the adjustments based on the settings for Scenario 3 results in the plot shown in Figure 7. From this figure, we see there were some unmeasured tributary adjustments for the cycle ending in 2015, along with some other adjustments. Subsequent graphs will show the source of the accepted deliveries and the other adjustments at the end of the first cycle.

Then for the second cycle, projected to end in 2020, the largest delivery adjustment was from the additional reservoir releases, followed by the unmeasured tributaries and the named-tributaries. Smaller adjustment deliveries were made from the Mexican return flow and from Mexico's portion of the spring inflow to Amistad. All other adjustments were minimal.

The graph in Figure 7 just shows the aggregated deliveries from the various sources. We will look in more detail at the main contributors to the adjustment deliveries in the following sections.

7.1.1 Deliveries from Mexican Reservoirs above Their Conservation Level

Figure 8 shows the adjustments applied to the system using water above the conservation levels at the Mexican reservoirs. For this simulation, only the Luis L. León dam on the Rio Conchos released water for this adjustment type.

7.1.2 Additional Deliveries from the Mexican Reservoirs

Figure 9 shows the additional water delivered from the Mexican reservoirs when they are below their conservation levels. For the first cycle, only Francisco I. Madero dam released water for this adjustment type. Then in the second cycle, larger releases for this adjustment-type were made at Luis L. León and Venustiano Carranza dams. There were also smaller releases for this adjustment made from La Fragua, San Miguel and Centenario dams in the second cycle.

The large change in storage resulting from adjustments at the Luis L. León dam is shown in Figure 10. Storage values that had previous been above the conservation level now drop below the conservation level, mainly due to the additional deliveries adjustments. The change in storage due to adjustments for Venustiano Carranza dam is shown in Figure 11.

7.1.3 Additional Deliveries from the Named-Tributaries

The graph in Figure 12 can be used to get an overall sense of the magnitude of the adjustments from each of the six named-tributaries. The accumulated deliveries from each of the named-tributaries, both as the observed values (dashed lines) and as the adjusted values (solid lines), are shown on this graph. In both cycles, there were some adjusted releases from Rio Conchos, and very slight adjustments from the other tributaries.

Since naturalized flow conditions were used for this scenario, Figure 13 shows the relative comparison for Rio Conchos between the median and 75% allotments of naturalized flow and the observed and adjusted delivery values. During the first cycle, the observed volumes start-out much lower than the MEDIAN naturalized flow statistical level and end slightly below the MEDIAN level. During the second cycle, the adjusted delivery line stays close to the MEDIAN statistical line throughout and ends slightly higher than the MEDIAN line.

7.1.4 Additional Deliveries from the Unmeasured Tributaries

The inflow from unmeasured tributaries is calculated based on the Accounting Reaches used by the IBWC. There are fourteen (14) Accounting Reaches with Reach 5 discharging into Amistad reservoir and Reach 9 discharging into Falcon reservoir. Figure 14 shows the delivery adjustments to the unmeasured inflows on a reach-by-reach basis for the first nine (9) reaches.

7.1.5 Additional Deliveries from Mexican Return Flow and Amistad Spring Inflow

Delivery adjustments from Mexican return flows and Amistad spring inflow are about the same, as shown in Figure 15.

7.1.6 Additional Deliveries from Rio Alamo and Rio San Juan

There were some accepted delivery adjustments in the first cycle, but no projected deliveries for the second cycle, as seen in Figure 16.

8 Conclusions

From the adjustment settings for Scenario 3, it appears the Additional Reservoir Releases from the Mexican reservoirs provides the largest amount of extra delivery to meet the *1944 Water Treaty*. However, the resulting consequences to the Mexican reservoirs may have a negative impact on Mexico's ability to meet its water-users demands. The unmeasured tributary inflow provides the next largest amount of adjusted delivery, is available on a reach-by-reach basis, and has no impact on the Mexican reservoir system.

This model can act as an invaluable tool in providing the U.S. and Mexican Sections of the IBWC a method based on science and technology to evaluate a complex system and consider the results of the proposed action. Working together, the U.S. and Mexico can jointly agree to adjustments that are acceptable to both countries to meet the target delivery specified by the *1944 Water Treaty*.

9 Limitations

As with all modeling endeavors, this model requires large amounts of data from both the U.S. and Mexican Sections of the IBWC. This data is not always available in a timely manner to run the simulation on a monthly or even quarterly basis, which would be the optimum time-frame for efficiently adjusting the water deliveries to meet the target while providing enough notice to the stakeholders in the U.S. and Mexico so that they can plan to use the water that will be available to them.

References

Treaty Series 994. (1946) Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande, *Treaty between the United States of American and Mexico*, Signed at Washington February 3, 1944, and Protocol, Signed at Washington November 14, 1944. Effective November 8, 1945. United States Government Printing Office, Washington:

Table 1: Scenario Adjustment Settings

Adjustment Types and Cycle Years (Available Water to Deliver)	Percent of Available Water to Deliver to the U.S.	Apply Adjustment when Delivery is Below this Percent of Target
Deliver water above conservation at Mexican reservoirs		
Year 1[1]	100	75
Year 2	100	75
Year 3	100	75
Year 4	100	75
Year 5	100	90
Deliver extra water from Mexican reservoirs		
Year 1	60	50
Year 2	70	50
Year 3	80	50
Year 4	90	75
Year 5	90	90
Deliver water from Rio Alamo and Rio San Juan		
Year 1	25	75
Year 2	25	75
Year 3	25	75
Year 4	25	75
Year 5	25	90
Increase U.S. share from named-tributaries		
Year 1	40	25
Year 2	40	25
Year 3	50	50
Year 4	60	75
Year 5	75	90

[1] Settings for years 1 through 5 apply to and are repeated for both five-year-cycles

Table 1: Scenario Adjustment Settings (con't)

Adjustment Types and Cycle Years (Available Water to Deliver)	Percent of Available Water to Deliver to the U.S.	Apply Adjustment when Delivery is Below this Percent of Target
Deliver portion of Mexico's share of unmeasured tributary inflow		
Year 1	0	25
Year 2	20	50
Year 3	40	50
Year 4	60	75
Year 5	80	90
Deliver portion of Mexico's return flow		
Year 1	10	25
Year 2	25	25
Year 3	50	50
Year 4	75	75
Year 5	90	90
Deliver portion of Mexico's share of spring inflow		
Year 1	0	25
Year 2	25	50
Year 3	50	50
Year 4	75	75
Year 5	90	90

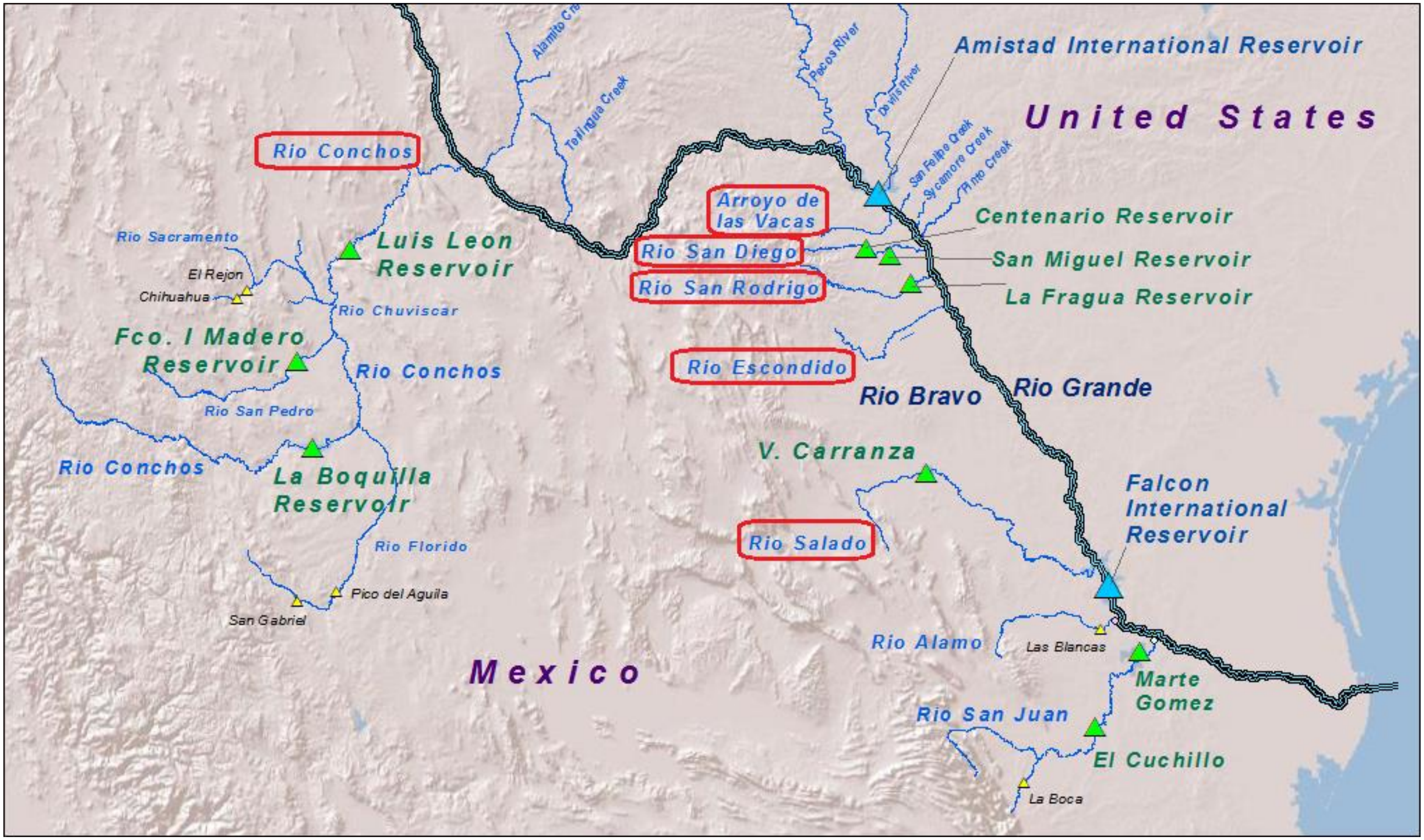

Figure 1: Map of study area, with major hydrologic components

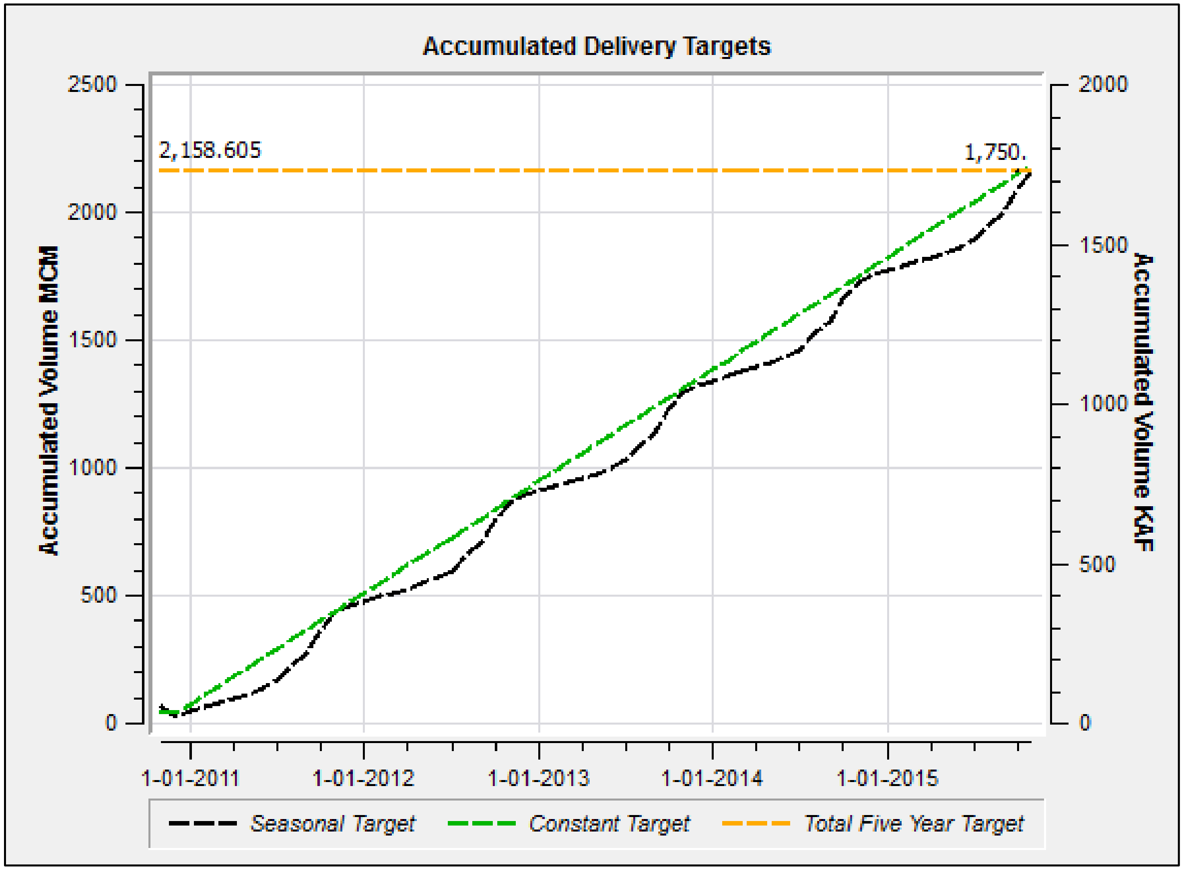

Figure 2: Accumulated Target Delivery Lines

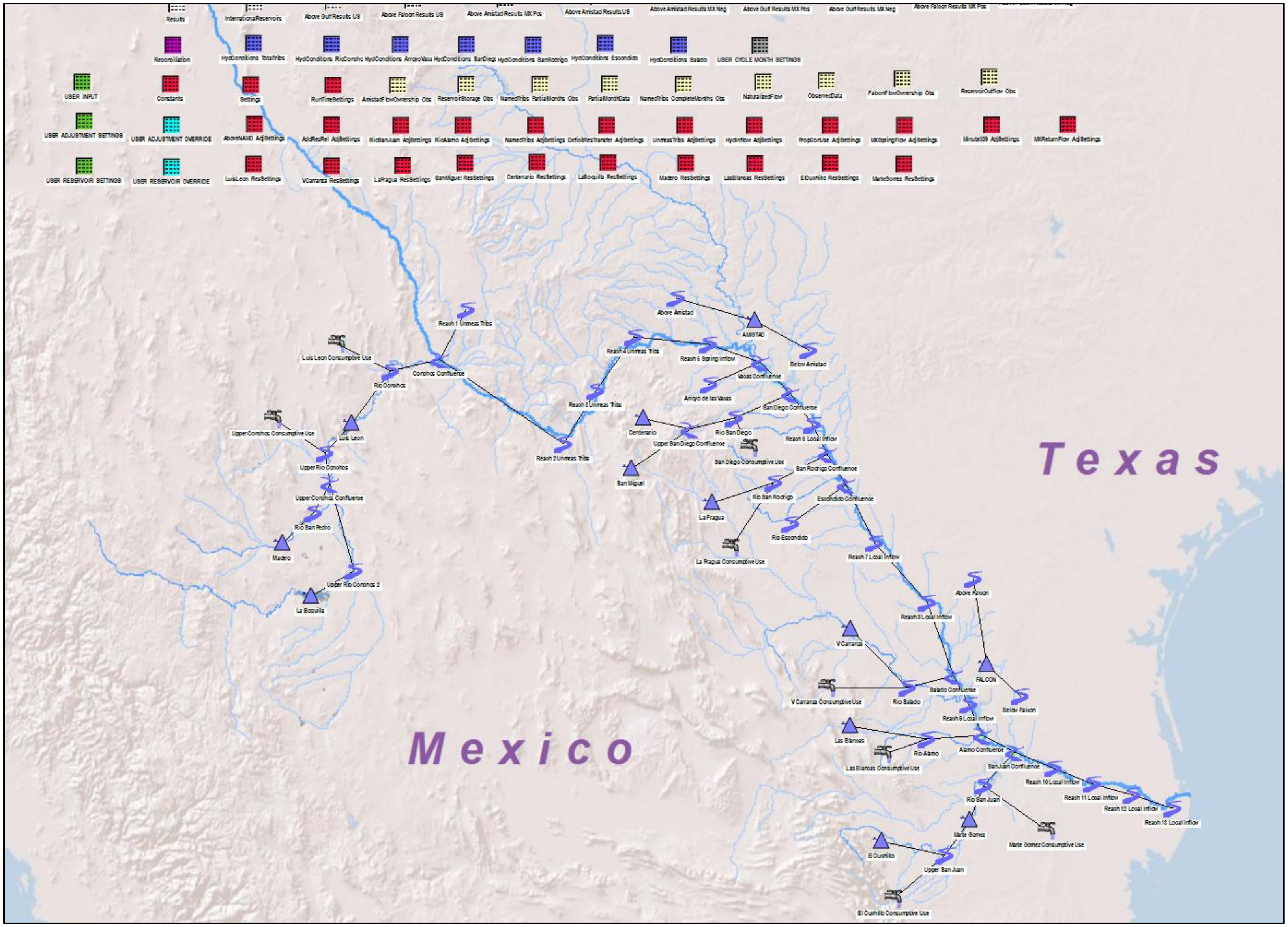

Figure 3: Layout of RiverWare Model

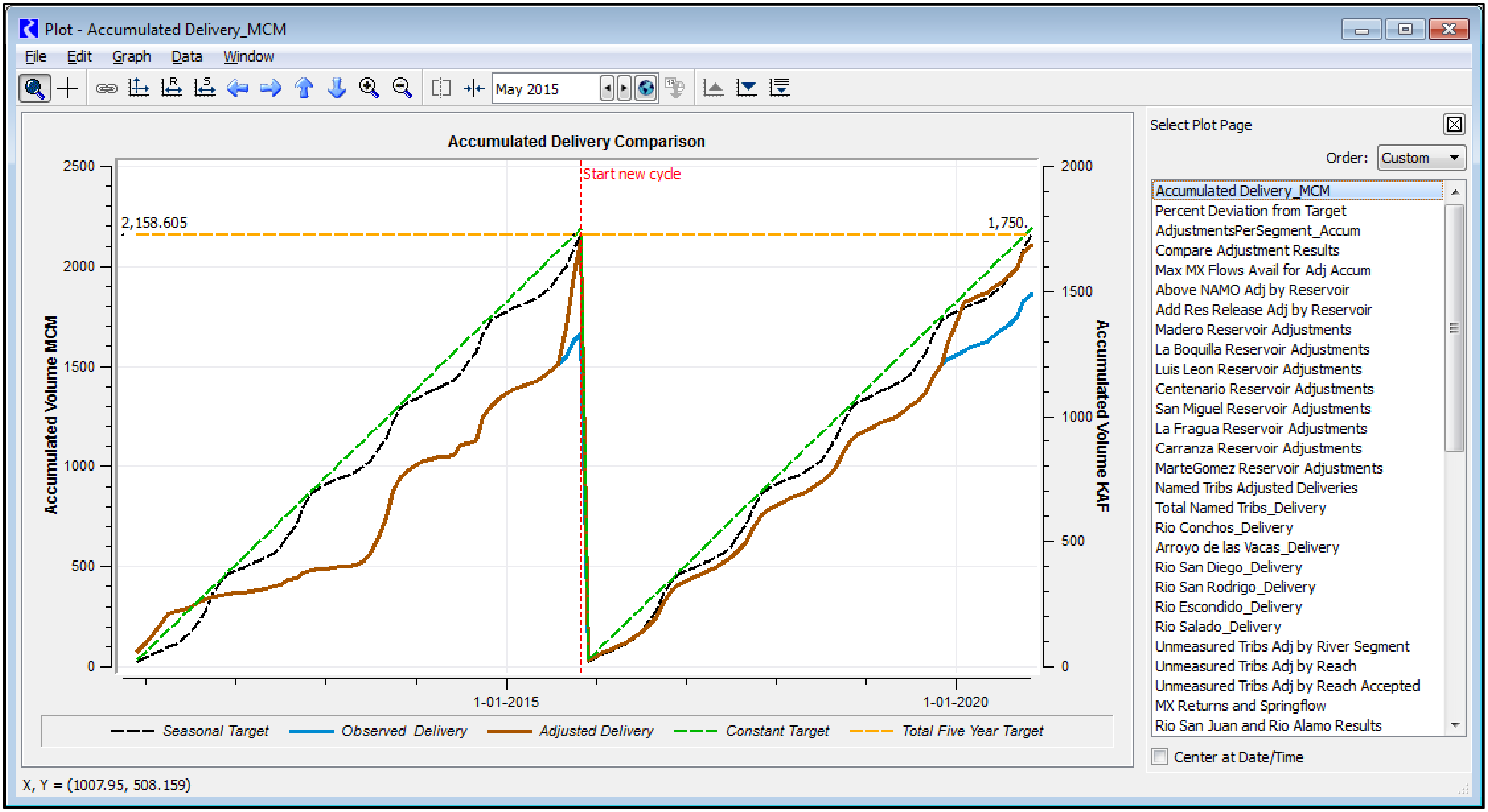

Figure 4: Scenario 1 – Accumulated Delivery Plot

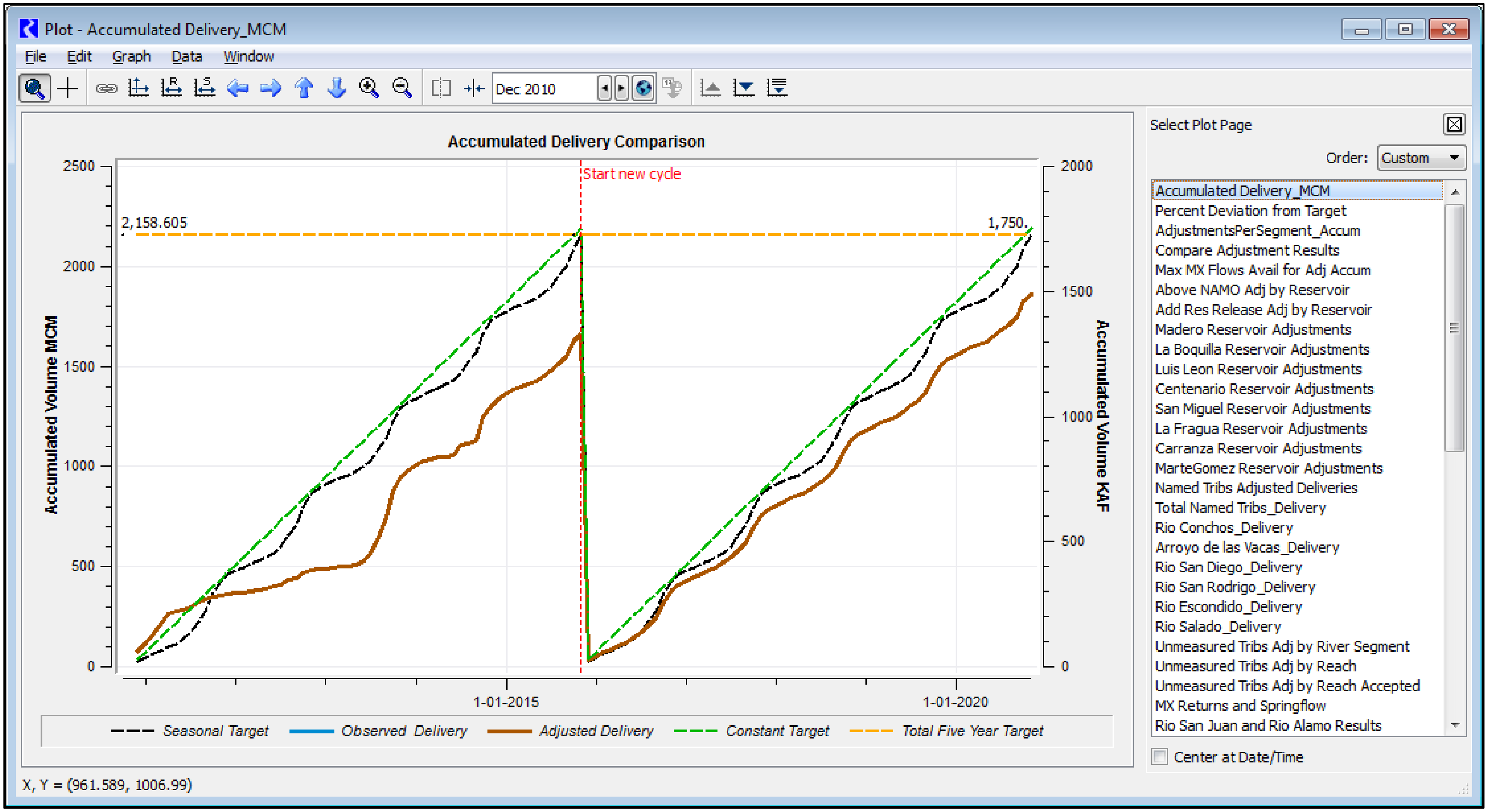

Figure 5: Scenario 2 – Accumulated Delivery Plot

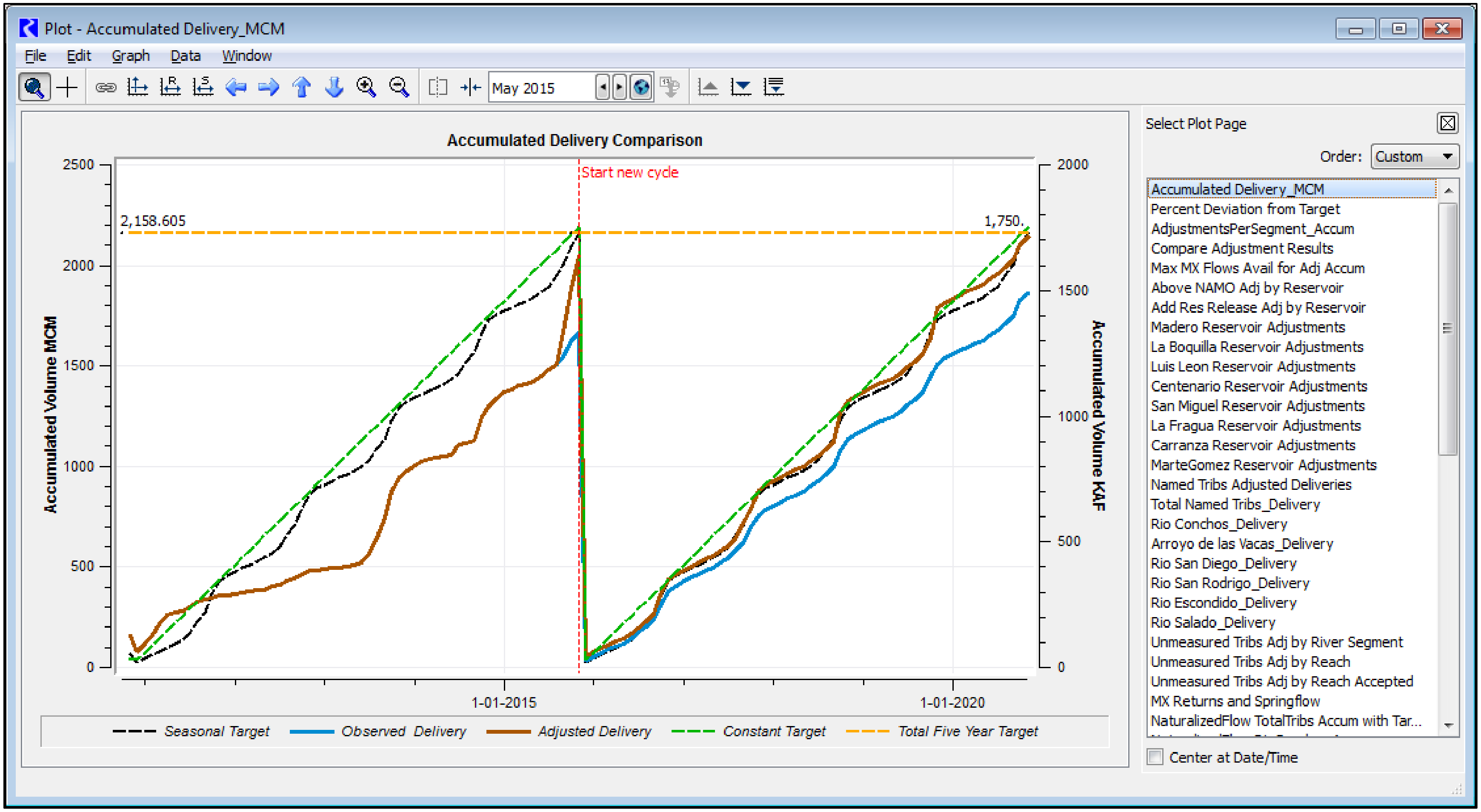

Figure 6: Scenario 3 – Accumulated Delivery Plot

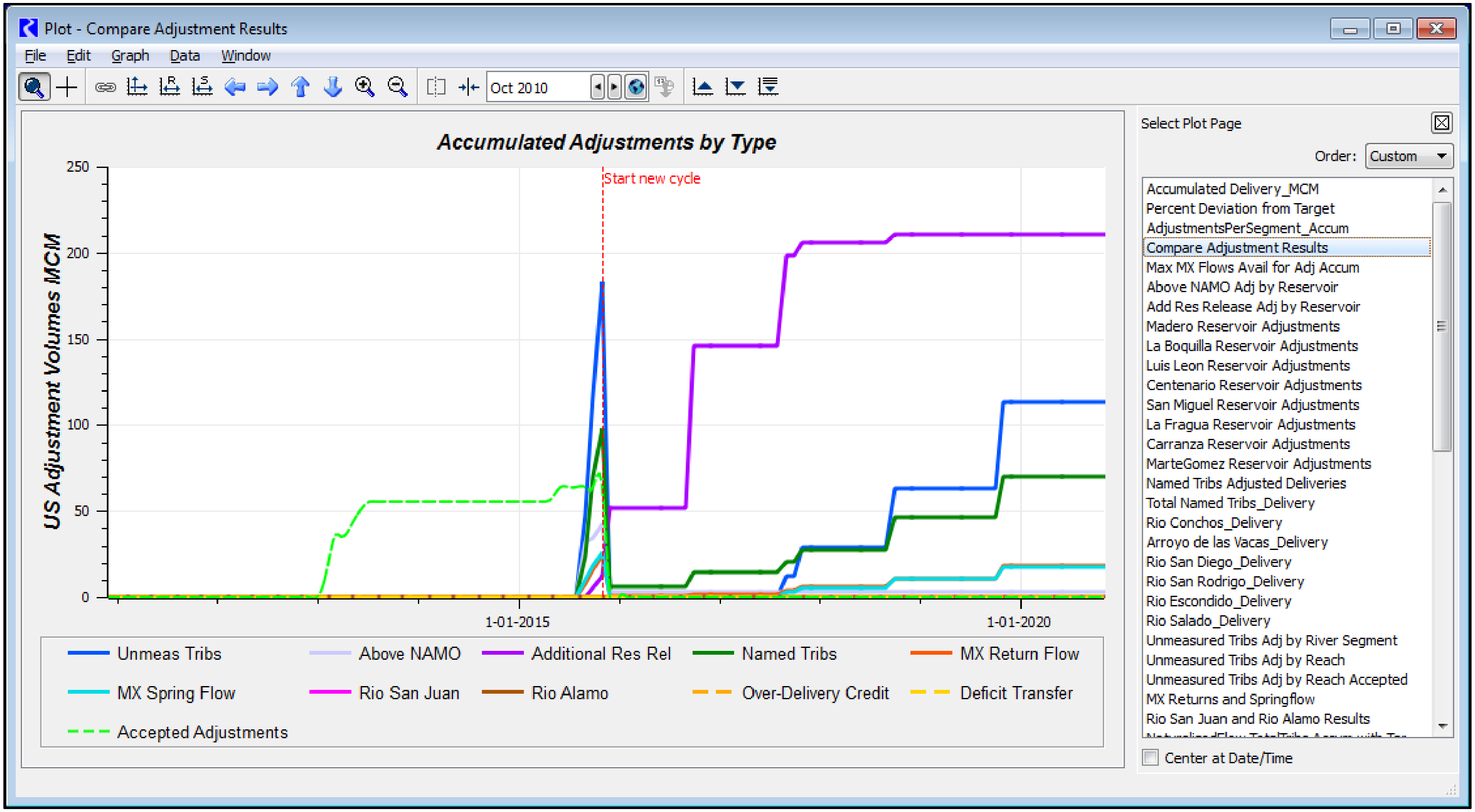

Figure 7: Scenario 3 – Accumulated Adjustments by Type

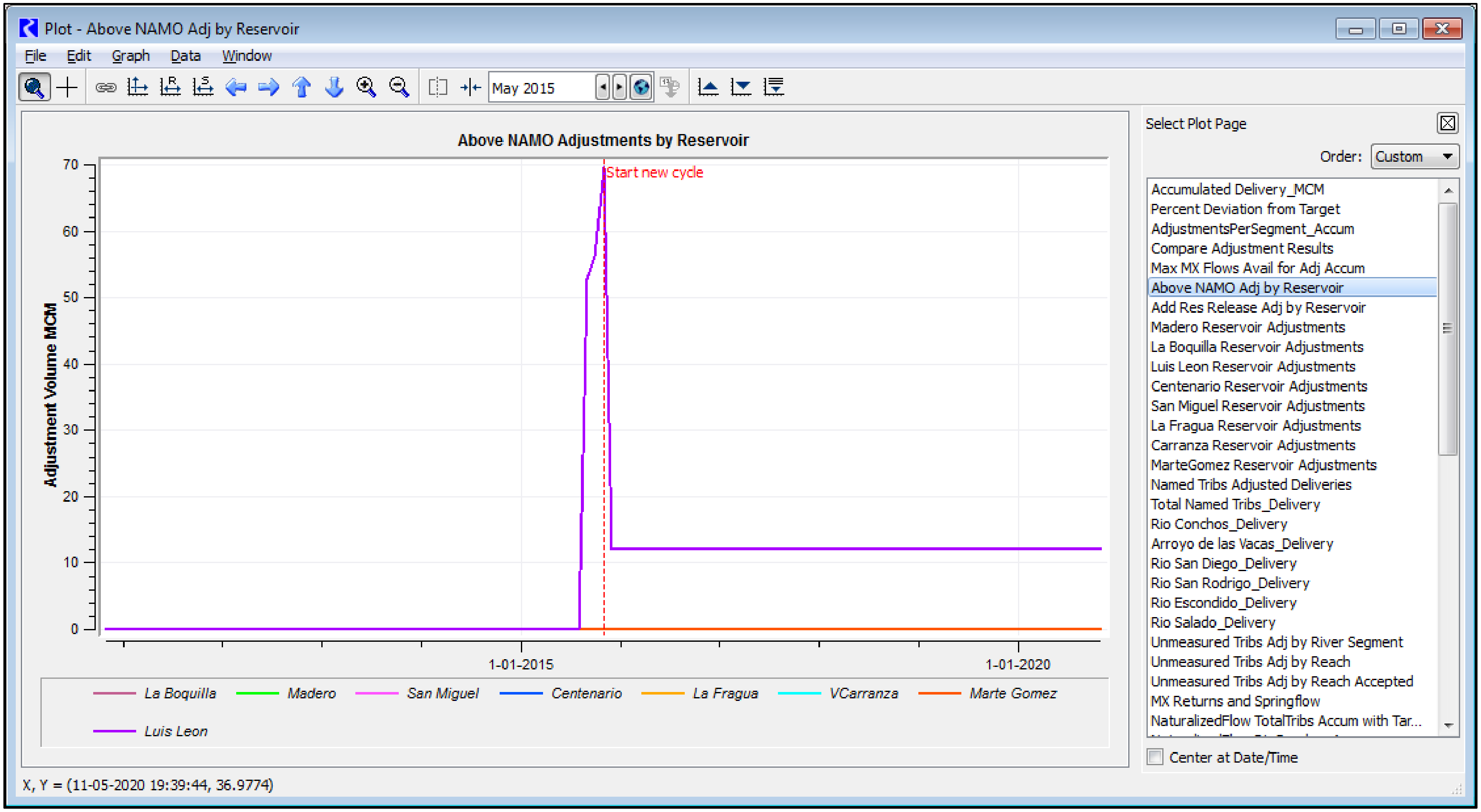

Figure 8: Scenario 3 – Deliveries from Mexican Reservoirs above Conservation Levels

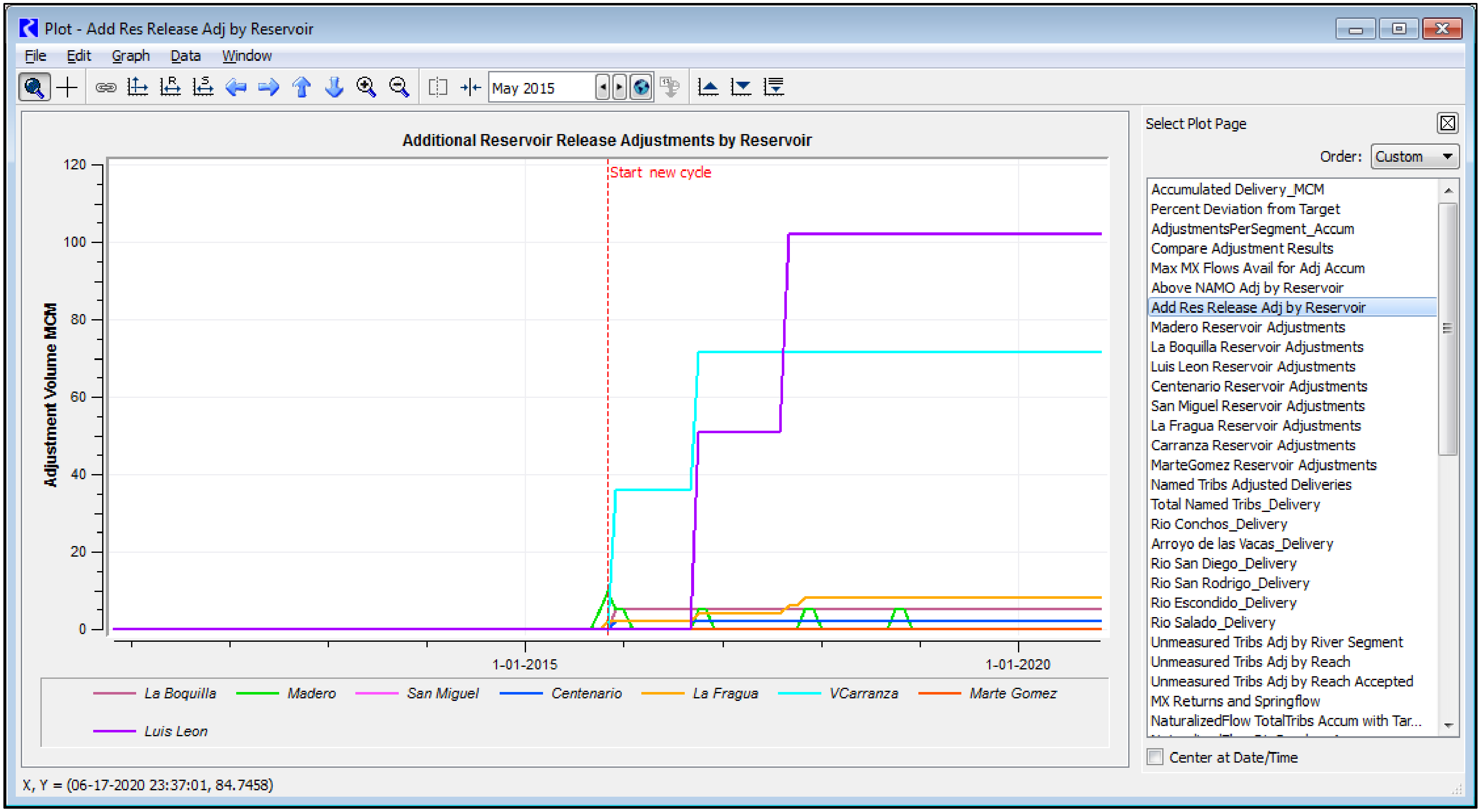

Figure 9: Scenario 3 – Additional Deliveries from Mexican Reservoirs

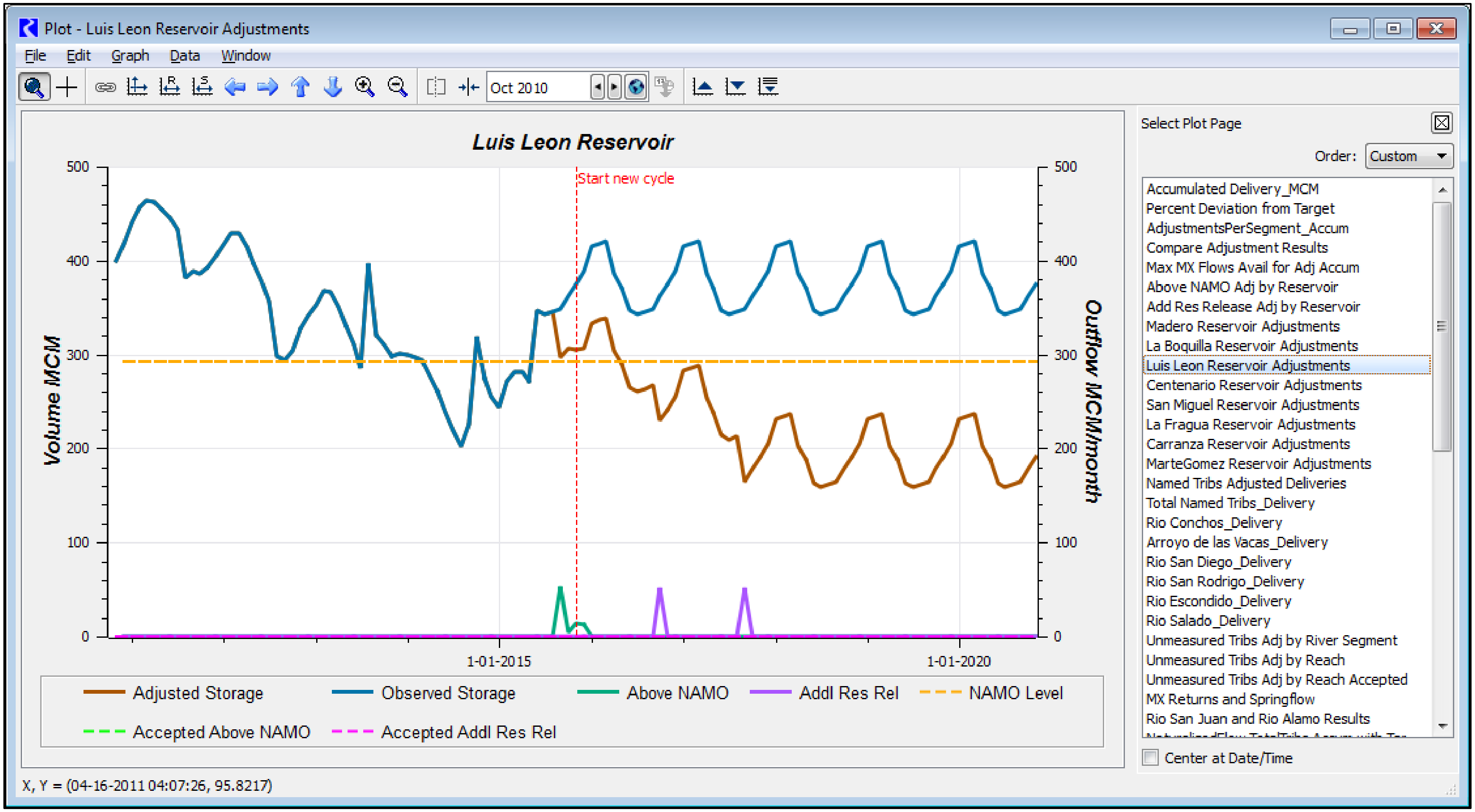

Figure 10: Scenario 3 – Adjustment to Luis L. León Reservoir Storage

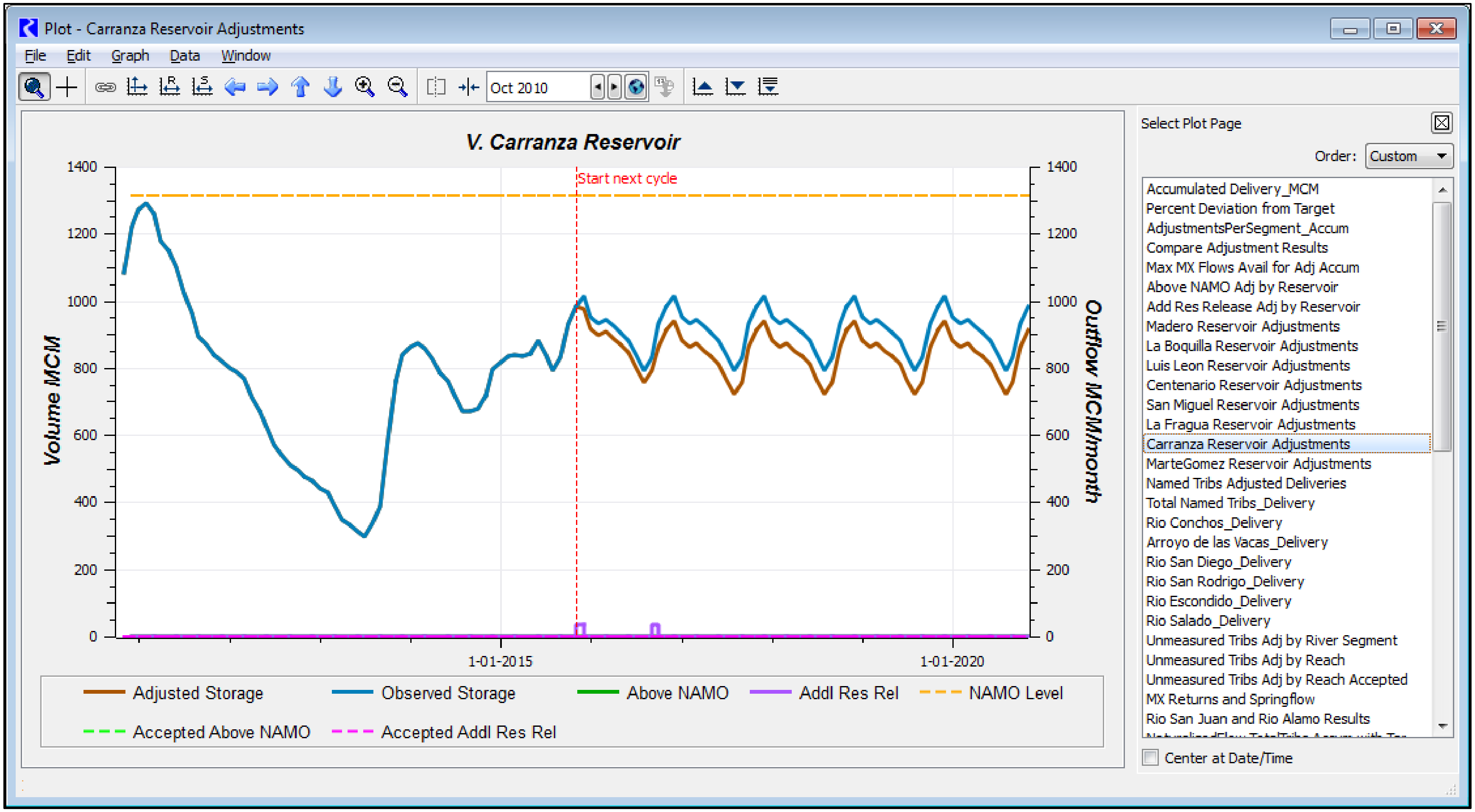

Figure 11: Scenario 3 – Adjustment to Venustiano Carranza Reservoir Storage

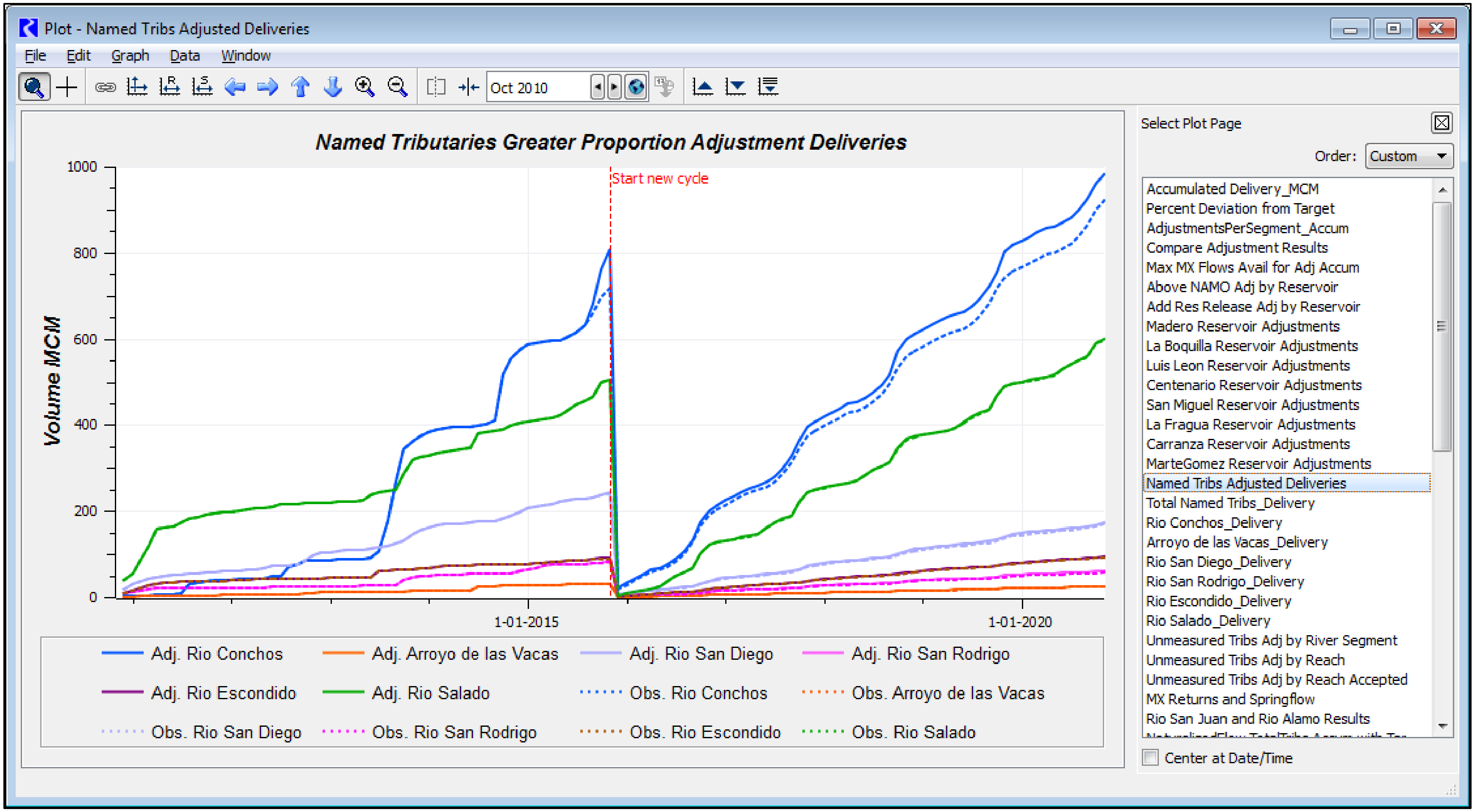

Figure 12: Scenario 3 – Adjustments to Named-Tributary Deliveries

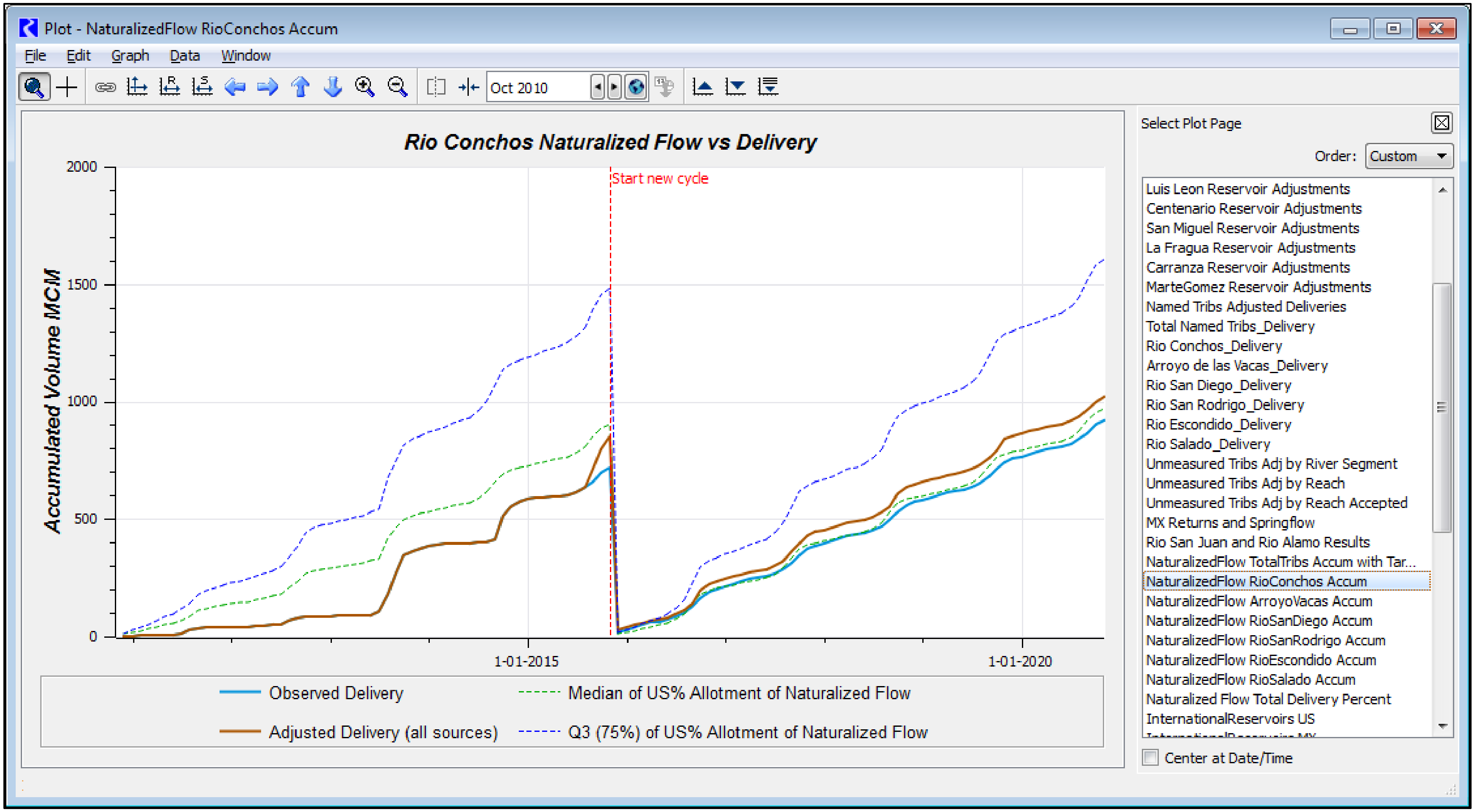

Figure 13: Scenario 3 – Rio Conchos Deliveries vs Naturalized Inflow Statistics

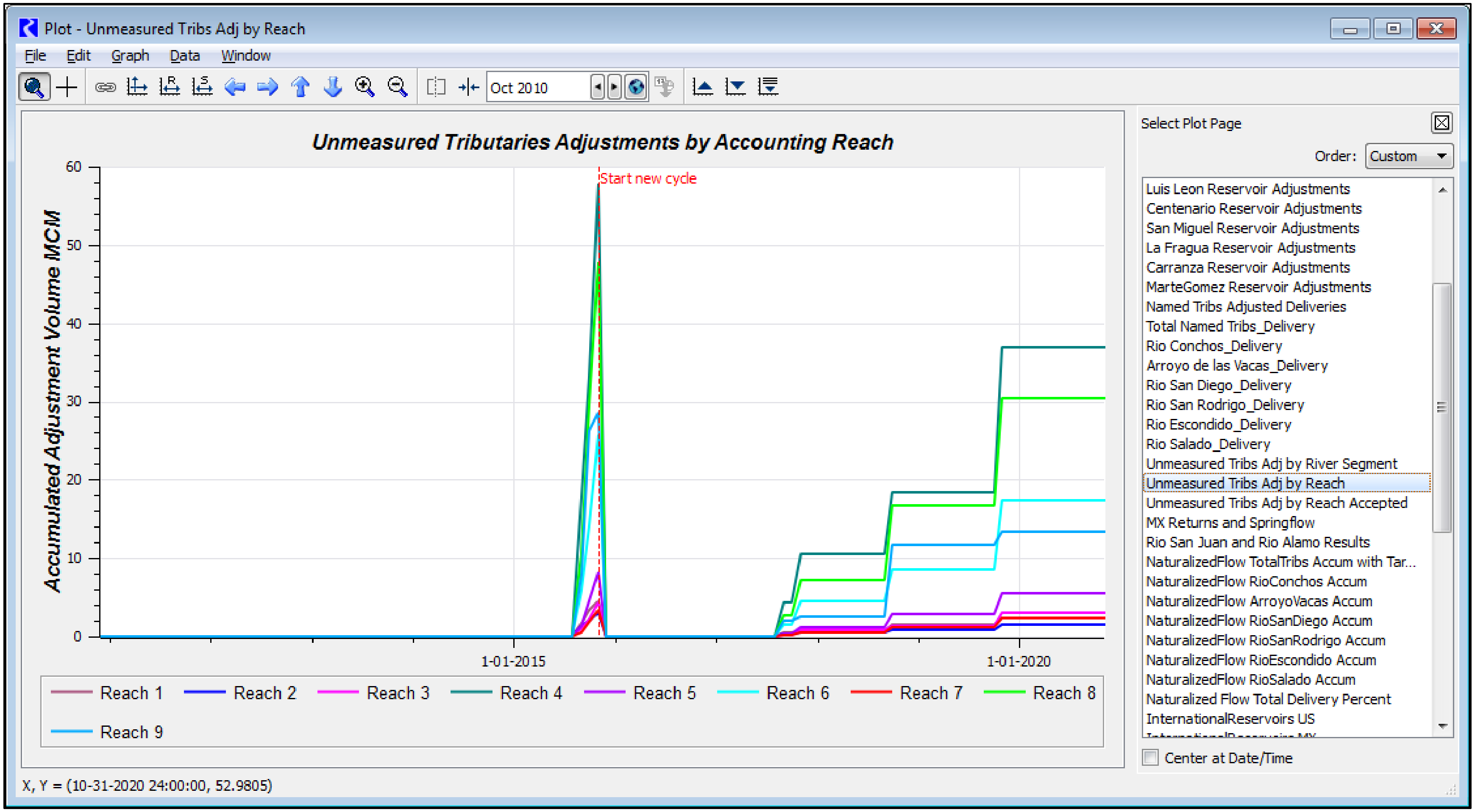

Figure 14: Scenario 3 – Adjustments to Unmeasured Tributaries Deliveries

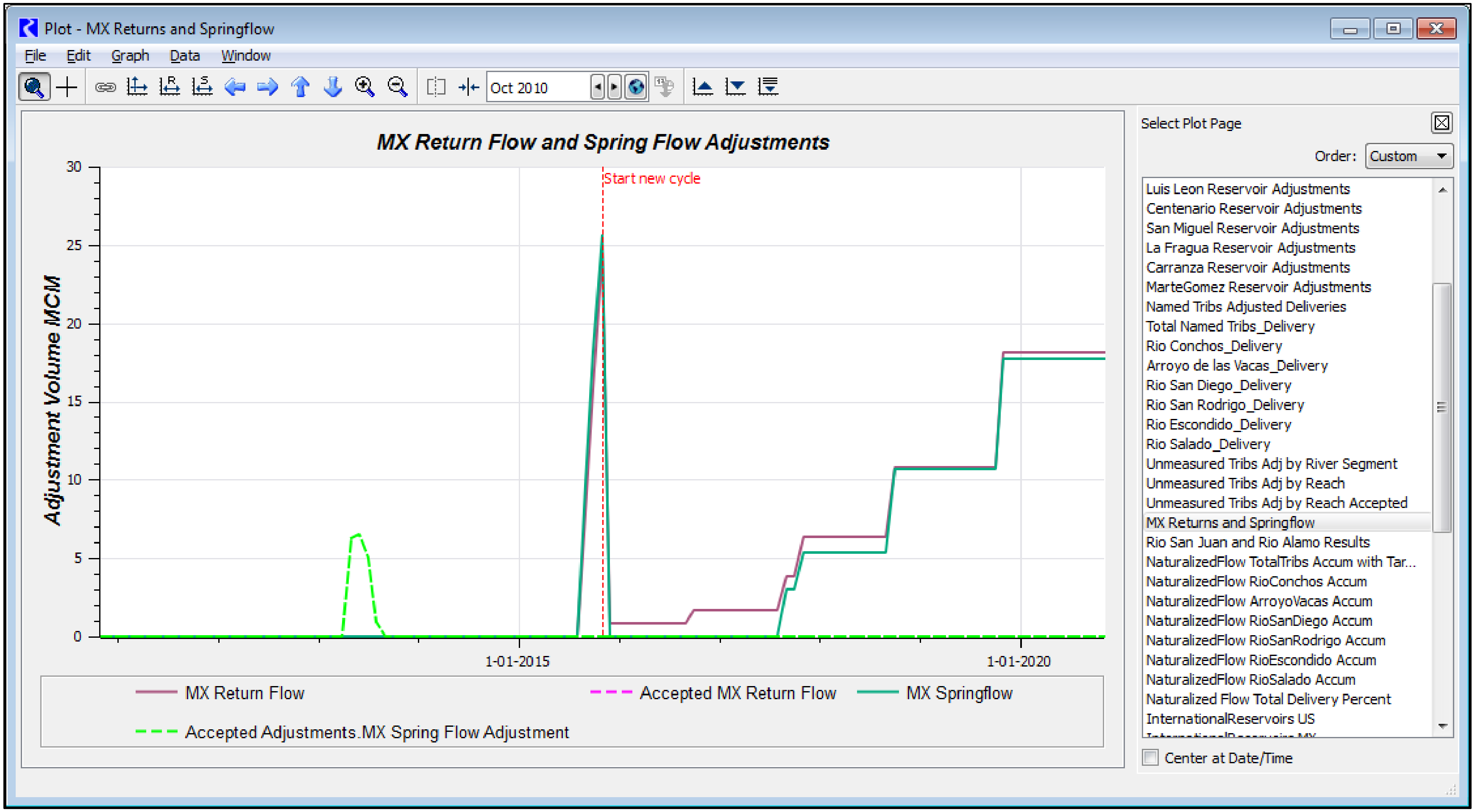

Figure 15: Scenario 3 – Adjustments to Mexican Return Flow and Spring Inflow

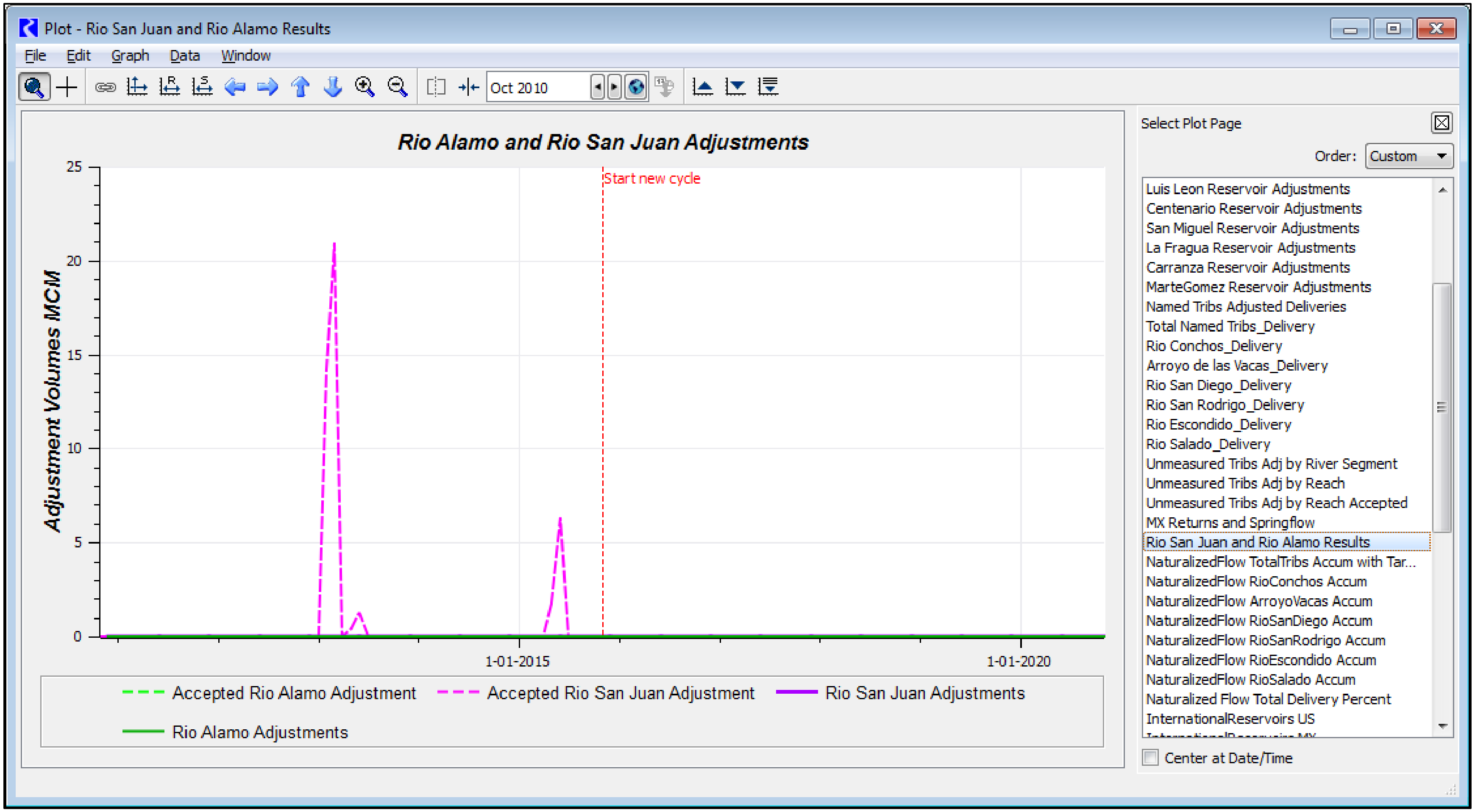

Figure 16: Scenario 3 – Adjustments to Rio Alamo and Rio San Juan