Research Report:

Beyond the limit, along the border

by:
Samuel Sandoval-Solis, Ph.D.,

October 2015

WATER MANAGEMENT RESEARCH LABORATORY

University of California, Davis
One Shield Ave. Dept. LAWR, Bldg. PES 1111 • Davis, CA 95616

This document is available online at
http://watermanagement.ucdavis.edu/e-library/

Beyond the limit, along the border

by Samuel Sandoval-Solis, PhD Candidate
Term Project: CE 387T - Decision, Risk and Reliability
The University of Texas at Austin

Introduction

Several problems have been identified in the Rio Grande/Bravo basin such as water quality, quantity, special and temporal variability of the water resources, over allocation of water rights, lack of specific regulation to allocate the water between the water users, extended drought periods, among others. Besides, there is a lack of standard parameters that can be used to evaluate if the policies implemented have been successful, or not. This document will focus its attention in obtaining a set of standard parameters to compare with and evaluate if they can be used to asses decision making.

Objective

1. Determine the performance expected for the treaty deliveries when the treaty of 1944 was signed.
2. Compare the historical performance against what was expected in the treaty.
3. Evaluate one alternative water allocation policy in the basin

Rules of the game

The treaty between United States and Mexico signed on February 3rd, 1944, defines the water allocation for the Colorado, Tijuana and Rio Grande/Bravo rivers (IBWC 1944). For the purpose of this exercise, we will focus our attention exclusively in the Rio Grande/Bravo River.

In summary, the U.S. has the ownership of:

- All the water reaching the Rio Grande/Bravo from two rivers (Pecos and Devils), one spring (Goodenought) and four creeks (Alamito, Terlingua, San Felipe and Pinto) whose headwaters are located in U.S. territory;
- 1/3 of the flow reaching the Rio Grande/Bravo from six Mexican tributaries (Conchos, Arroyo Las Vacas, San Diego, San Rodrigo, Escondido and Salado), provided that this third shall not be less, as an average amount in cycles of 5 consecutive years, than 431.721×10^6 m^3/year, although such one third may exceed this amount; and
- ½ of all other flows not otherwise allotted along the Rio Grande/Bravo River.

Mexico has the ownership of:

- All the waters reaching the Rio Grande/Bravo from 2 rivers (San Juan and Alamo) including the return flows from lands irrigated from these rivers;
- 2/3 of the flow reaching the Rio Grande from the six Mexican tributaries listed above (Conchos, Arroyo Las Vacas, San Diego, San Rodrigo, Escondido and Salado); and
- ½ half of all other flows not otherwise allotted occurring along the Rio Grande/Bravo River.

Two international dams were built to store these water, Falcon (1952) and Amistad (1968). <u>The treaty cycles can expire earlier than five years if the conservation capacity assigned to the United States in both international dams is filled with water belonging to the United States</u>.

Pre-treaty signature analysis (1944)

Before the treaty was signed, several analyses were done in order to evaluate the feasibility of what will be stated in the treaty of 1944. The technical report presented by Orive (1945) to the Chamber of Senators shows the calculations considered before the treaty was ratified by the Chamber. For the purpose of water planning and management, it is important to know these calculations to figure out what was the performance expected for treaty deliveries from Mexico to the U.S. One objective of this exercise is to define the performance expected before the treaty was signed. For this purpose, we are going to use 3 performance criteria: Reliability, Resilience and Vulnerability.

Reliability refers to the frequency in time an event is successful in relation to the total period of time analyzed. We define a successful event as the event when there is no deficit in the delivery of treaty obligations. Resilience is the probability that once the system is in a deficit, the next period the system recover to a successful event. Vulnerability is the expected value of the deficits, in other words, it is the average of the deficits experienced. With these three performance criteria we are going to analyze the treaty obligations. Further description of these parameters is explained in Appendix A.

Two different cases were considered by Orive to evaluate the treaty obligations. Case I only considers 5 years cycles, before the dam's construction, when the system is considered to not be fully developed; and Case II, which considers that in wet years the treaty cycles expires earlier because the conservation capacity assigned to the U.S. is filled. This consideration happens when the dams have been constructed and the system is considered to be fully developed. Table 1 shows the reliability, resilience and vulnerability for both cases. For Case I, when the system is not fully developed, the reliability is 56%, which means they expected that 44% of the time the system will be on a deficit; a resilience of 65% which means that 2 out 3 times the system will recover from a deficit in the following period; and a vulnerability of 10%, which means that the average deficit was expected to be only 10% of the total amount compromised. For Case II when the system is fully developed, as it is now, the reliability expected was 42%, indicating that 58% of the time they expected to be on a deficit, a resilience of 80% means that 4 out of 5 times they expected the system will recover from a deficit in the following treaty cycle, and a vulnerability of 9% indicates that the average deficit they expected was about 9% of the total treaty obligations. Appendix B shows the calculations for these results.

Table 1. Reliability, Resilience and Vulnerability expected for the Treaty of 1944

	Case I System Not Fully Developed	Case II System Fully Developed
Reliability	56%	42%
Resilience	65%	80%
Vulnerability	10%	9%

From the previous results, three assumptions can be made. First, it was expected that the system will be constantly in a deficit, in fact, very frequently, about half of the time. Second, it was also expected that the system will recover very frequently, mostly by the occurrence of wet periods. In that time, it was acknowledged the high variability of the basin, considering the dry periods when treaty deficits were expected and wet periods when early expiration cycles were expected. Also, in a broad perspective, the system was set to be managed in a 2 treaty cycle period rather than a 1 treaty cycle period. In fact, Orive (1945) considered a successful event when a deficit cycle was followed by a non deficit cycle. Third, it was acknowledge that the not all the times it could possible to met the treaty obligations; however, deficits were expected to be small, only 10% of the total amount. Besides, it was considered that these deficits could be covered without any problem or harm to the water users. **In conclusion, the treaty of 1944 was signed relying in the high resilience and low vulnerability of the system, rather than in the reliability of the system.**

Post-treaty signature analysis (1953-2007)

In this section, we are going to compare the reliability, resilience and vulnerability of the historic treaty performance against the expected values when the treaty was signed for the two cases: Case I when the system was not fully developed; and Case II when the system was fully developed. Appendix C shows the calculations for the historic data. Table 2 shows the comparison for Case I (Oct/1953 to Sep/1968). As can be seen, the system was less time in deficit (higher reliability) than what was expected; besides, the system recover faster than what was expected (higher resilience); however, the average deficit was bigger than what was expected (higher vulnerability).

Table 3 shows the results for case II (Oct/1968 to Sep/2007). Similar than case I, the system was less time in deficit (higher reliability) than what was expected. In contrast, in this case the system recovers slower than what was expected (lower resilience) and once again the average deficit was bigger than what was expected (higher vulnerability).

Table 2. Comparison of Reliability, Resilience and Vulnerability, between the historic and the expected treaty values, **Case I: System not fully developed**

	Expected Values Treaty 1944	Historical Treaty Performance (1953-1968)
Reliability	56%	67%
Resilience	65%	100%
Vulnerability	10%	27%

Table 3. Comparison of Reliability, Resilience and Vulnerability between the historic and the expected treaty values, **Case II: System fully developed**

	Expected Values Treaty 1944	Historical Treaty Performance (1969-2007)
Reliability	42%	61%
Resilience	80%	75%
Vulnerability	9%	22%

On one hand, the treaty obligations were properly delivered more frequently than what was expected (higher reliability) and; on the other hand, the quickness of coming back from a deficit period was not as fast as it was expected (lower resilience), and the deficits were bigger than the values considered (higher vulnerability). These results are against the original treaty deliveries schema that was supported on a high resilience and a low vulnerability. **In conclusion, the historical treaty deliveries showed that the system cannot rely in the premises of high resilience and low vulnerability.**

From now on, we are going to focus our attention in Case II, when the system is fully developed, because that is the actual condition of the basin. To evaluate this case in detail, the period of time is divided in 3 sub-periods which has a length between 10 to 15 years. The length of each period is different in order to match the beginning and ending of the cycles. Table 4 shows the group of cycles evaluated.

Figure 1, Figure 2 and Figure 3 show the results of reliability, resilience and vulnerability for the group of cycles selected. Figure 1 shows the reliability for most of the cycles was acceptable, except for the cycles 25 to 27, when an extended and severe drought happened in the basin. Following the same trend, the resilience (Figure 2) for all the cycles is acceptable, except for the cycles 25 to 27, when a two consecutive deficit cycle happened. As a result, the resilience for the cycles 4 to 27 was also unacceptable. The period of time that comprehends cycles 25 to 27 (Oct

92 to Sept07) is considered one of the worst droughts periods in the basin, just less severe than the record drought of the 50's (1947-1957).

Table 4. Groups of treaty cycles

Cycle	Period Beginning	Period Ending	Duration (years)
4 to 11	Oct-68	Jun-81	12.7
12 to 24	Jun-81	Sep-92	11.3
25 to 27	Sep-92	Sep-07	15.0
28 to 29	Oct-07	Feb-09	1.4
4 to 27	**Oct-68**	**Sep-07**	**39.0**

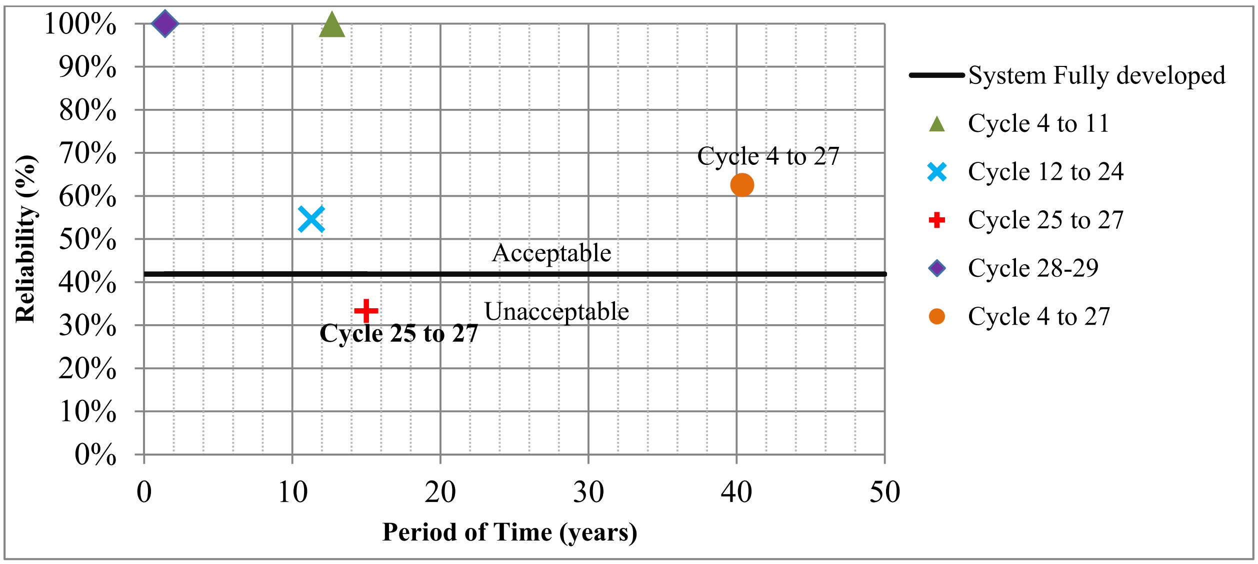

Figure 1. Historic reliability by group of cycles

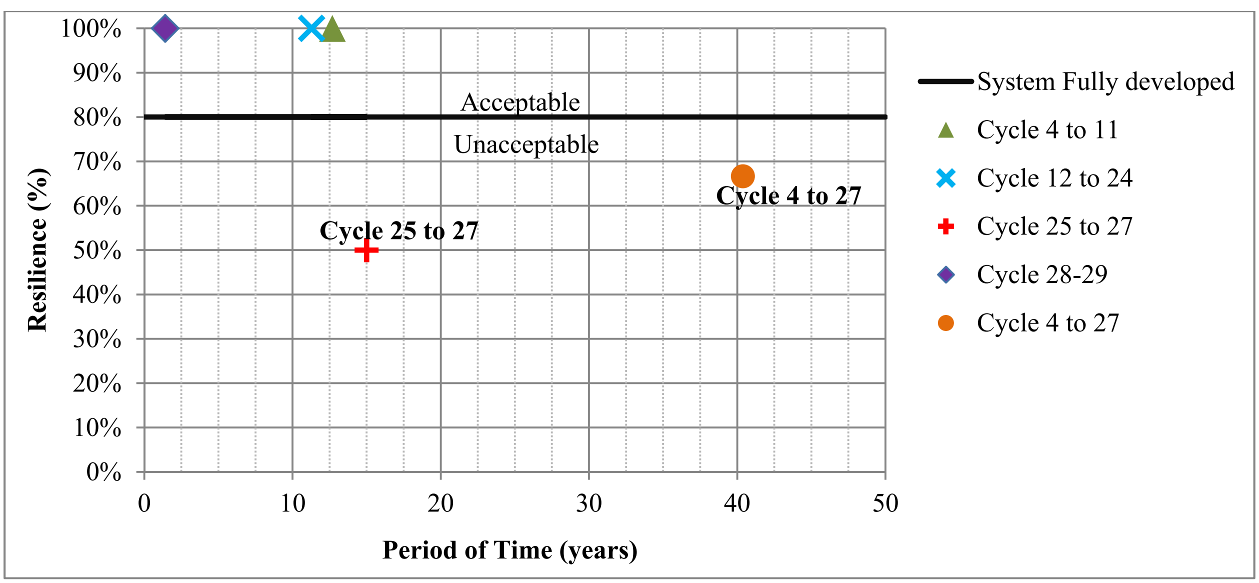

Figure 2. Historic resilience by group of cycles

Figure 3 shows the vulnerability for the group of cycles selected. As can be seen, in all the periods, except in cycles 4 to 8 when no deficit happened, the vulnerability is higher than the value expected when the treaty was signed. Notice that for the cycle 25 to 27, the vulnerability is almost 40%, four times larger than the value expected of 9%.

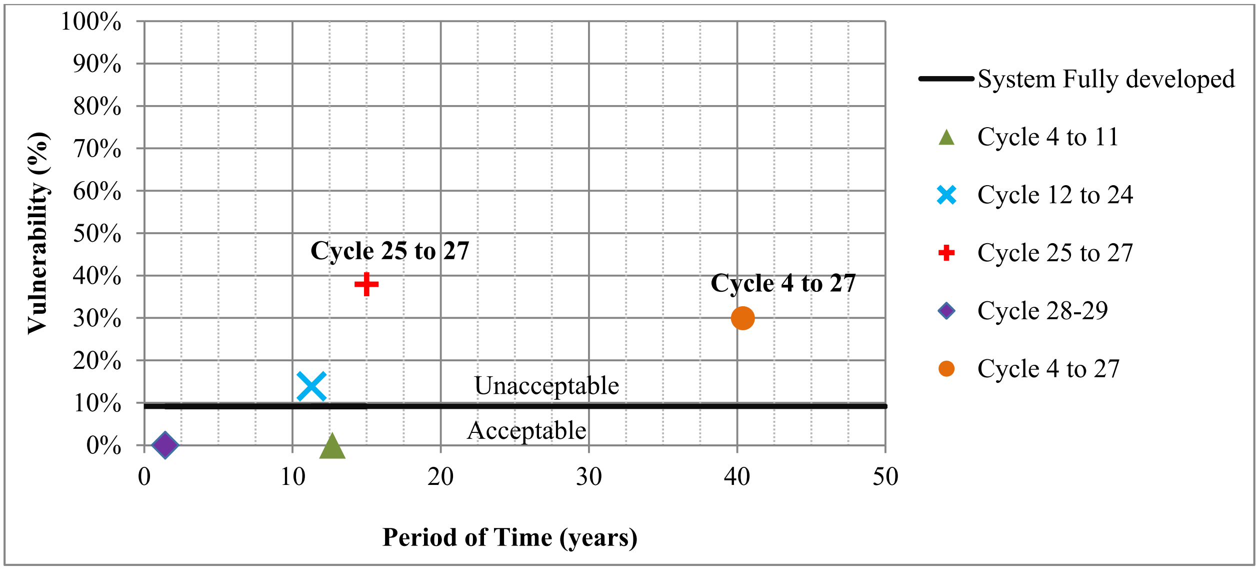

Figure 3. Historic vulnerability by group of cycles

The previous results show that **under drought conditions, the system does not recover as fast as what was expected**, because of the droughts length (> 10 years), i.e. cycle 25 to 27 (Sep/1992 to Sep/2007). Besides, **the expected deficits are bigger than what was estimated** and under drought conditions these deficits can be significantly big to threat the water management for water users and the treaty obligations.

Looking into the future (>2004)

The problem of high vulnerability for the treaty obligations was evident in cycles 25 to 27, when the deficit stood up to 59% at the end of cycle 25 (1263 million m^3) and up to 17% in cycle 26 (376 million m^3). Short and long term policies took place in ordered to meet the treaty obligations.

In the short term, measures such as the delivery of water from dams to the treaty obligations and the assignment of Mexico's storage volumes in the international dams in favor to the United States took place in order to reduce the treaty deficits (IBWC/CILA 2001 & 2002). In the long term, several policies took and are taking place such as the increase in the efficiency of irrigation district (IBWC/CILA 2001); the buy-back of water rights to reduce the over allocation of water rights; and the strict delivery of the water right volume specified in the water concession and not a variable amount that used to be more than the water right volume specified in the concession.

From the long term policies, *the strict delivery of the water rights volume specified in the water concession* is in process to take place. This policy does not need a significant financial investment but it requires a lot of political effort to convince the farmers to use only the water that is specified in their water rights concession and not a variable amount that most of the times used to be more than their water right. In this section, we are going to analyze this policy and compare it against the performance of the historic treaty deliveries.

Statement of the problem

The National Water Commission of Mexico (CONAGUA) is evaluating the implementation of a strict water management policy that will deliver at most, the water volume specified in the water right for each water user, and not a variable amount that can be higher than the water right (Status Quo), as historically used to happened.

An historical analysis of the treaty deliveries for the Status Quo has shown that the probability to get a deficit in the treaty obligations is 0.39. A hydrologic planning model that simulates the Rio Grande/Bravo basin has been built to evaluate different water management policies in the basin. According to the researchers, the model has an 85% confidence that the model work in the full scale. Results from the model determined that the probability to have a deficit with the strict policy is 0.17. If the model does not work, it can be assumed that the probability of deficit will be the same as the Status Quo.

Costs of Benefits, Vulnerability and Resilience will be used to evaluate both policies. Table 5 shows the Reliability, Probability of deficit, Vulnerability and Resilience for the Status Quo and the Strict Policy. The data for the Status Quo come from Table 3 and the data from the Strict Policy come from the model results.

Table 5. Reliability Resilience and Vulnerability, Status Quo and Strict Policy

	Reliability (%)	P(Deficit) (%)	Vulnerability (%)	Resilience (%)
Status Quo	61%	39%	22%	75%
Strict Policy	83%	17%	38%	50%

The Benefit cost ($Benef) is defined as the average annual value that represents the water management without being in a deficit. Benefits may include: environmental, social, economic and political benefits. This cost has a positive sign and is expressed in monetary units per year (+$/year). The Vulnerability cost ($Vuln) is defined as the average annual value that represent being in a deficit condition. It also represents the ravages that the water user are subject to when the basin is in a deficit condition. This cost has a negative sign and is expressed in monetary units per year (-$/year). The resilience cost ($Resil) is defined as the average annual cost necessary to get the system out of a deficit condition. This cost has a negative sign and is expressed in monetary units per year (-$/year).

Two utility functions were defined to evaluate the vulnerability and resilience:

$$U(Vulnerability) = \frac{Vulnerability_i}{Vulnerability_{Historic}}; \quad U(Resilience) = 1 - \left(\frac{Resilience_i - Resilience_{Historic}}{Resilience_{Historic}} \right)$$

The Vulnerability utility functions compare the vulnerability of the *i*-eth policy proposed with the historical vulnerability value. This function will penalize if the vulnerability is higher than the historical value and reward if the vulnerability is lower than the historical values. Similarly, the Resilience utility function compares the resilience of the i-eth policy proposed with the historical resilience value. This function will penalize if the resilience is lower than the historical value and reward if the resilience is higher than the historical value. Table 6 shows the utility functions values for the Status Quo and the Strict Policy. Figure 4 shows the decision tree for the problem.

Table 6. Utility functions of Vulnerability and Resilience

	U(Vulnerability)	U(Resilience)
Status Quo	1.00	1.00
Strict Policy	1.69	1.33

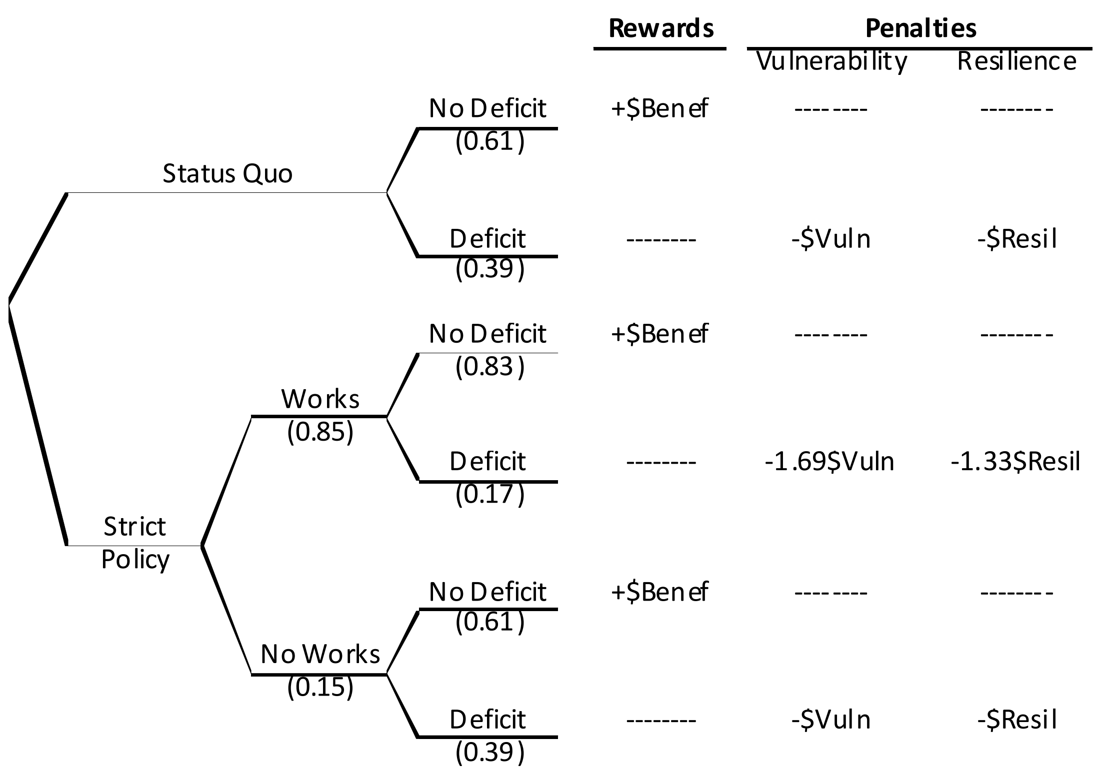

Figure 4. Decision tree

The expected monetary value (EMV) for the Status Quo is defined by the equation:

EMV(Status Quo) = +(0.61)$Benef/year - (0.39)$Vuln/year - (0.39)$Resil/year

The EMV if the results of the model Works and No Works are defined as follows:

EMV(Works) = +(0.85) $Benef?year - (0.28)$Vuln/year - (0.23)$Resil/year

EMV(No Work) = +(0.61)$Benef/year - (0.39)$Vuln/year - (0.39)$Resil/year

The EMV for the Strict policy is defined as follows:

EMV(Strict Policy) = (0.85)EMV(Works) + 0.15EMV(No Works)

EMV(Strict Policy) = +(0.81)$Benef/year - (0.30)$Vuln/year - (0.25)$Resil/year

If we compare the coefficients in the EMV equations for the Status Quo and the Strict Policy, the benefits per year in the Strict Policy are higher than in the Status Quo (0.81>0.61). Besides, the penalties per year due to the Vulnerability (0.30<0.39) and Resilience (0.25<0.39) are lower than in the Status Quo. **Thus, it is recommendable to adopt the strict policy promoted by CONAGUA.**

Discussion

From the previous analysis, several topics are analyzed and discussed in this section:

1. The policy proposed is compared with the historical data and not with the values expected when the treaty was signed (1944). In this case, the reason is that the policy proposed must be compared with data from the real system, rather than against calculations when the system was not built. However, is good to know these values, in order to know what the goals are in the water planning and management. Because of the briefness of this document, the comparison of the Strict Policy against the 1944 values will not be shown.

2. The utility functions were defined to estimate in which percentage the vulnerability and resilience increase or decrease, with respect to the historical values. Two reasons were considered for this assumption. First, it is possible to estimate the monetary damage because of the deficits (vulnerability cost) and the monetary value to recover from a deficit (resilience cost) on average per year, according to the historical records. Second, the evaluation is based on a system of penalties and rewards.

3. Talking about the Reliability, notice this parameter was used as the probability of *No deficit* in both policies. Furthermore, the reliability for the Strict Policy is significantly

higher than the reliability for the Status Quo. Some explanations must be done to clarify this behavior. The hydrological period of analysis run in the model is 1940-2000, which is a longer than the historical period compared with, 1969-2007. This mismatch in the periods may cause problems in the reliability calculation, because the reliability relies in the length of the period analyzed. However, the period used in the model includes the record drought of the 50's (1948-1958), the drought of the 60's (1961-1965) and most of the recent drought of the 90's (1992-2002). Thus, even though the conditions evaluated in the model are more severe than the historical conditions analyzed, the reliability for the strict policy is still significantly higher.

4. Talking about the vulnerability, notice this parameter increased in the strict policy. Basically, only two deficits happened in the simulation of the strict policy, one in the drought of the 50's (1950-1955) with a magnitude of 41%, and the second in the drought of the 90's (1995-2000) with a magnitude of 35%. These deficits are lower than the historical record deficit in cycle 25 of 59%, which corresponds to the drought of the 90's. Thus, even though the vulnerability index in the strict policy is worse than in the historic conditions, the droughts will be less in frequency, and lower than the historic record.

5. Besides, notice that if the model "*No Works*", it was considered the same probabilities (reliability) as the status quo, implying that the hydrologic conditions will be the same in the future. Considering the climate change, this assumption is not very likely. However, the methodology defined in this document is such a flexible that has room to include the climate change evaluation in posterior analysis.

6. Finally, in this analysis it was possible to determine which alternative is recommendable without defining specific monetary values, something that is very convenient. However, a more detailed economic analysis should be done to validate or correct this analysis done.

Conclusions

All the objectives were achieved: 1) Performance criteria parameters of reliability, resilience and vulnerability for the pre-treaty signature were defined. These values are important in order to know the goals considered when the treaty was signed. 2) The historical treaty delivery was evaluated and compared with the pre-treaty parameters. This comparison shows that the system is "*Beyond the limit, on the border*", because several times the parameter values do not meet the standards defined for the pre-treaty signature, and 3) These parameters were successfully used to evaluate one alternative water management policy in the Rio Grande/Bravo basin.

References

IBWC/CILA (1944). “Treaty Between the United States and Mexico. Utilization of waters of the Colorado and Tijuana Rivers and of the Rio Grande” International Boundary and Water Commission. November 14, 1944. Washington D.C. <http://www.ibwc.state.gov/Files/1944Treaty.pdf >.

Orive Alba, Adolfo (1945). “Informe técnico sobre el tratado internacional de aguas” Comisión Nacional de Irrigación. México D.F., Sep. 1945.

IBWC/CILA (2001) Minute 307: Partial Coverage of Allocation of the Rio Grande Treaty Tributary Water Deficit From Fort Quitman to Falcon Dam. Mach 16, 2001 http://www.ibwc.state.gov/Files/Minutes/Min307.pdf

IBWC/CILA (2002) Minute 308: United States Allocation of Rio Grande Waters During the last Year of the Current Cycle. June 28, 2002. http://www.ibwc.state.gov/Files/Minutes/Minute308.pdf

IBWC/CILA (2003) Minute 309: Volumes of water saved with the modernization and improved technology projects for the irrigation districts in the Rio Conchos Basin and measures for their conveyance to the Rio Grande. July 3, 2003. < http://www.ibwc.state.gov/Files/Minutes/Min309.pdf>