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Applying Economic-Engineering Systems Analysis to the Colorado River Delta

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ABSTRACT

Recent decades have seen increasing urban, agricultural, and environmental demands for water from the Lower Colorado River Delta ("CRD") in Mexico. At the same time, there has been increased interest in restoring this delta environment. Balancing these competing interests involves a complex variety of integrated environmental, economic, engineering, and legal issues. One approach to these complex problems is systems analysis, which attempts to quantify many of these factors and their inter-relationships. The CALVIN (California Value Integrated Network) model is a systems analysis tool developed and successfully applied for strategic water management in California. The CALVIN model optimizes and integrates water operations and allocation based on costs and economic scarcity of water for urban and agricultural users. The CALVIN model provides promising insights for water management regarding water markets, facility expansion, dam removal, conjunctive use, economic costs of environmental restrictions, and users' economic willingness to pay for water. Mexico's Lower Colorado River Delta is suitable for analysis using CALVIN because inter-boundary water issues, water scarcity, economics, and restoration efforts are integral to water resources management in this region. If optimally configured, dedicated flows for restoration in the CRD could result in low opportunity costs for agricultural and urban users. The CALVIN model offers a novel approach to water resources management and restoration that takes into account hydrology, institutional constraints, management infra-structure, and the economic value of water in a region.

I. INTRODUCTION

The Lower Colorado River Delta in Mexico faces a continuous struggle for water among a variety of users. As in many other parts of the world, agriculture uses the majority of water in the CRD, followed by a handful of fast-growing cities near the U.S.-Mexico border. The U.S.-Mexico Water Treaty of 1944

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allocates water from the Colorado River to Mexico. Some researchers argue that only a small amount of water is needed to retain or restore CRD ecosystems. According to those researchers, about 32,000 thousand acre-feet ("TAF") per year with pulse flow volumes of 240,000 TAF would suffice.[1] Nevertheless, even a small amount of water can cause conflict among the other Colorado River water users. Thus, many disciplines will find their niche in the amalgam of environmental, legal, economic, and engineering aspects of CRD water resources management.

Quantification of complex systems can often result in a more precise and integrated understanding of problems and potential solutions. This quantitative understanding commonly takes the form of a computer model. Computer models are valuable for many water resource systems,[2] as well as in business and industry where accounting systems, data, and flow models form the foundation for daily operations, planning, and policy studies.

This article discusses the early development of a quantitative understanding of some major economic, engineering, and hydrologic aspects of CRD restoration issues. This quantification takes place within the framework of the CALVIN computer model. CALVIN offers a novel approach to such a complex water resource management problem. The CALVIN model is a systems analysis tool that was developed and successfully applied in California. CALVIN applications in California include users' willingness to pay for additional water, economic cost of environmental restrictions, dam removal, conjunctive use, facility expansions, and conveyance and water transfers. The CRD is suitable for analysis using CALVIN since transboundary water issues, water scarcity, economics, and restoration efforts are integral to water resources management as the CRD region is similar to California. The CALVIN model offers an integrated quantitative understanding of CRD water management issues, and can suggest economically promising solutions through optimization using systems analysis. Model development and results can improve and integrate understanding of CRD problems on a large scale, and start a cycle of improvement for understanding and managing possibilities for these problems. For the CRD in particular, it is hypothesized that increased dedicated flows, suggested by some research, may impose only small economic costs for agricultural and urban water users.

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1. DANIEL F. LUECKE ET AL., A DELTA ONCE MORE: RESTORING RIPARIAN AND WETLAND HABITAT IN THE COLORADO RIVER DELTA (1999).

2. John W. Labadie, *Reservoir System Optimization Models*, 108 WATER RESOURCES UPDATE 83 (1997).

II. THE CALIFORNIA VALUE INTEGRATED NETWORK ("CALVIN") MODEL

CALVIN is a little unusual as an optimization model. Most water resource models are simulations,[3] meaning they answer very specific "what if?" questions, such as, "what would happen if we change the minimum flow in a river by a specified amount, and all other things remain constant?" However, for some problems, one can use the model to suggest how a variety of decisions could be changed to result in a "better" solution. These optimization models pursue answers to "what's best" questions by prescribing "best" or "optimal" strategies, assuming a certain degree of flexibility and coordination within the system at hand. Optimization models are appealing where problems: (1) have quantifiable objectives; (2) are describable by a tractable mathematical model; (3) have sufficient data to characterize the effects of alternative solutions; and (4) are without an obvious best alternative.[4] In essence, an optimization model is a simulation model with the addition of: (a) an explicit quantitative index of performance (an objective or overall cost function), and (b) a clever mathematical algorithm that can efficiently search through feasible management decisions to identify the solution that performs "best."

The outputs from many types of optimization models include information beyond the "optimum" solution or set of decisions. For models solved by several common techniques (linear, network flow, and some types of non-linear algorithms), the marginal costs of all constraints on the system are also produced. These would include the marginal value (in terms of the performance objective) of small changes in facility capacities, minimum instream flows, inflows, water demands, and water allocation policies. This sensitivity analysis information can be useful in understanding the physical or policy limits to better management solutions, and how expensive these limits are in terms of the performance objective of the model.[5]

A. *The CALVIN Model in Brief*

CALVIN is an economic-engineering optimization model that explicitly integrates operation of water facilities, resources, and demands for California's intertwined system.[6] The CALVIN model uses network flow optimization to find the minimum-cost operation of a particular system. HEC-PRM is a program

3. *Id.*

4. DOUGLAS HAITH, ENVIRONMENTAL SYSTEMS OPTIMIZATION (1982).

5. Stacy K. Tanaka & Jay R. Lund, *Effects of Increased Delta Exports on Sacramento Valley's Economy and Water Management*, 39 J. AM. WATER RESOURCES ASS'N 1506 (2003).

6. Marion W. Jenkins et al., *Optimization of California's Water Supply System: Results and Insights*, 130 J. WATER RESOURCES PLAN. & MGMT. 271 (2004); Andrew J. Draper et al., *Economic-Engineering Optimization for California Water Management*, 121 J. WATER RESOURCES PLAN. & MGMT. 155 (2003).

developed by the U.S. Army Corps of Engineers that is used to minimize the cost of the entire network by solving the following set of equations:

Minimize: The total cost of the system $Z = \sum_i c_{ij} X_{uj}$

Subject to: mass conservation for all nodes j; $\sum_i X_{ji} = \sum_i a_{ij} X_{ij} + b_j,$

a maximum flow $X_{ij} \leq u_{ij}$, for all arcs;

a minimum flow $X_{ij} \geq l_{ij}$ for all arcs;

where Z is the total cost of flows throughout the network, X_{ij} is flow leaving node i towards node j, c_{ij} is the economic cost, b_j are the external inflows to node j, a_{ij} is the gain/loss on flows in arc ij, u_{ij} is the upper bound on arc ij, and l_{ij} is the lower bound on arc ij.[7] The economic cost or value of water not flowing through an arc is also known as a penalty (Fig. 1).

The basic idea is to assign an economic cost to water scarcity for each agricultural or urban demand node in a region. Each of these demand nodes is designated a water delivery target; water delivery in any amount less than the target will impose an economic cost, which will accumulate in the total system cost in Z above (Fig. 1). Penalty functions in CALVIN are of at least[8] of two types: agricultural and urban.

Economic value of water deliveries for agriculture uses the State Wide Agricultural Production model ("SWAP"). The SWAP is a separate optimization model that maximizes farm profit for each agricultural demand area, given a quadratic crop production function with water, land, technology, and capital inputs, as well as constraints on water and land availability.[9]

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7. MARION W. JENKINS ET AL., IMPROVING CALIFORNIA WATER MANAGEMENT: OPTIMIZING VALUE AND FLEXIBILITY, CENTER FOR ENVIRONMENTAL AND WATER RESOURCES ENGINEERING REPORT NO. 01-1 (2001).

8. Examples of other penalties include water quality considerations, hydropower (benefit) and/or increased pumping cost in overexploited aquifers.

9. Draper, *supra* note 6; RICHARD E. HOWITT ET AL., IMPACTS OF CLIMATE CHANGE ON CALIFORNIA'S AGRICULTURAL DEMANDS (2003).

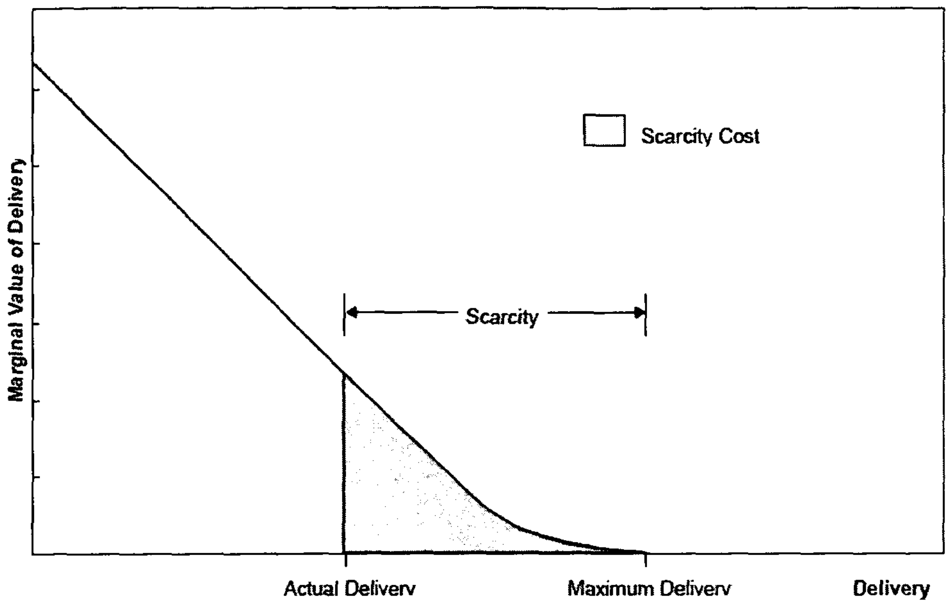

Figure 1. Definitions of scarcity and scarcity cost for economic demands.[10]

Urban economic values for water use are estimated using constant price-elasticity of demand curves. Price-elasticity values vary between summer, winter, and intermediate months.[11]

The CALVIN model uses surface and ground water hydrology, information on facilities and capacities, environmental flow constraints, urban and agricultural values of water, and operating costs (Fig. 2). This information is stored in a set of databases, which include documentation on the origins and limitations of these data. These databases are inputted to the HEC-PRM flow optimization software, solving the general equations above, and producing solution and some sensitivity outputs. The CALVIN model provides information on economic benefits of water, potential conjunctive use and cooperative operations, willingness to pay for additional water, water operations and delivery reliabilities, value of flexible operations, and value of increase capacities (Fig. 2).

10. Brad D. Newlin et al., *Southern California Water Markets: Potential and Limitations*, 128 J. WATER RESOURCES PLAN. & MGMT. 21 (2002).

11. Estimation of demand curves and penalty functions are detailed in Jenkins, *supra* note 6.

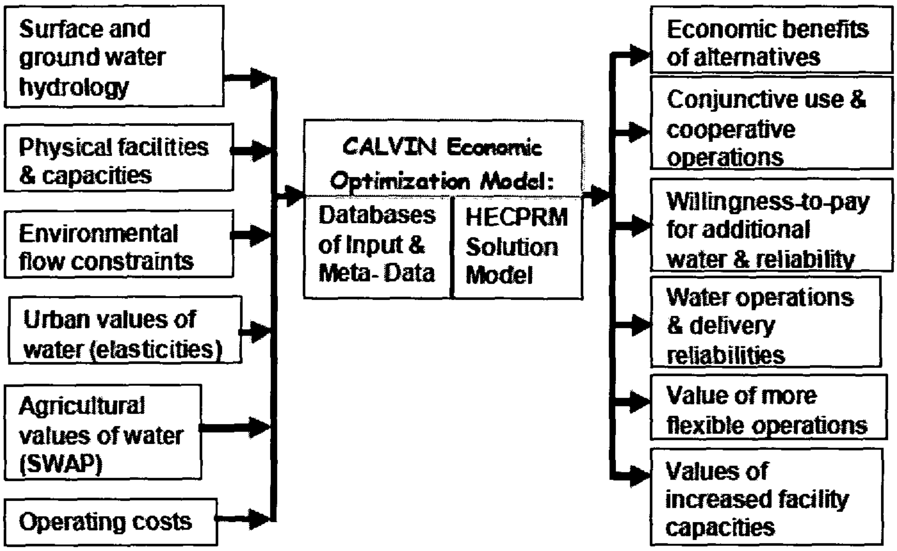

Figure 2. Data flow schematic for the CALVIN model.[12]

The hydrology is represented by a seventy-two year (1921-1993) time series of monthly inflows data. Operating costs include both fixed and variable costs for pumping, treatment, recharge, and wastewater recycling. Environmental constraints typically represent minimum flow regimes required to maintain ecosystems in selected locations. Maximum flow constraints normally refer to conveyance infrastructure capacity.

Currently, CALVIN divides California into five regions that represent about 92% of the state's population, and 88% of its irrigated acreage (Fig. 3). These regions are the Upper Sacramento Valley, the Lower Sacramento Valley and Bay Delta, San Joaquin and South Bay, Tulare Basin, and Southern California. The five regions in CALVIN can be either modeled separately or as one large network.[13] For the full statewide model of California, solved over the seventy-two year range of hydrology, the model solves over a million decisions.

12. HOWITT, *supra* note 9.

13. Draper, *supra* note 6.

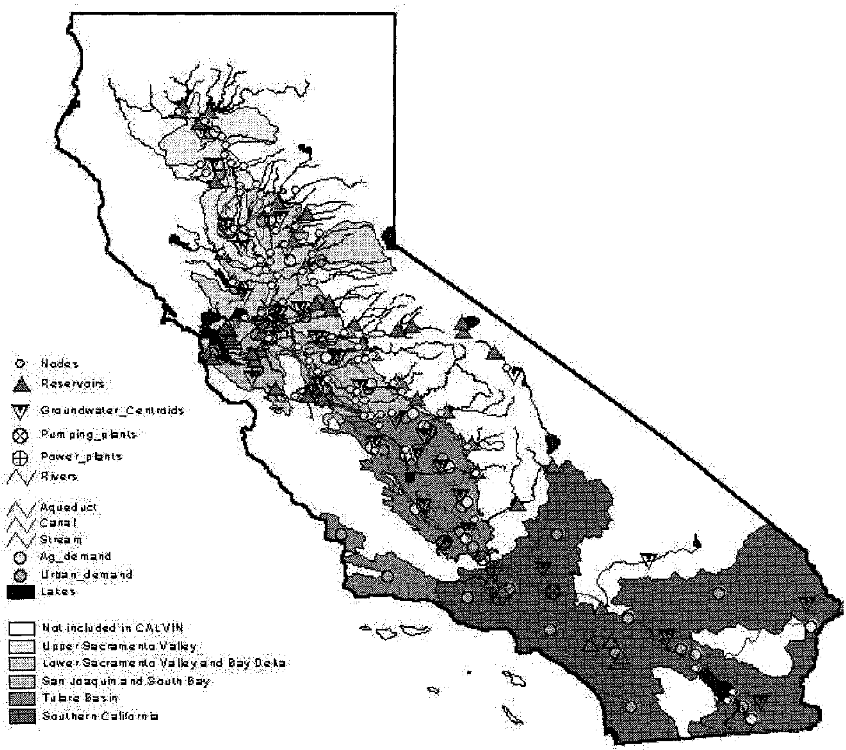

Figure 3. Agricultural and urban demand regions represented in CALVIN.[14]

B. *Applications and Insights for Water Management Resources*

The CALVIN model runs typically include a base case ("BC"), which represents current operating practices and allocation policies, a regional case with economically driven operations for each of the five regions, and a statewide case with economically driven operations and allocations.[15] Economically driven alternatives can be regional and statewide ideal water markets. Table 1 shows total cost for the three model runs in CALVIN estimated water demand and supply levels in 2020. Significant total cost drops can be seen by departing from the BC toward the other two laissez-faire scenarios. Nevertheless, only small gains can be seen when moving from a regional to a statewide water management scenario.

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14. *Id.*
15. Jenkins, *supra* note 6; Draper, *supra* note 6.

Table 1. Regional and Statewide Total Cost Performance.[16]

	Average total cost ($M/year)		
Region	BC	RWM	SWM
Upper Sacramento Valley	35	34	29
Lower Sacramento and Delta	212	166	166
San Joaquin and Bay Area	394	358	333
Tulare Lake Basin	461	434	415
Southern California	3,074	1,855	1,838
Total	4,176	2,847	2,780

Note: BC – base case; RWM – regional water market; and SWM – statewide water market

Using the CALVIN model, ideal water markets in Southern California dramatically drop the average total scarcity cost in that region from $1596 million to $279 million per year.[17] Willingness to pay for additional water ranges from nothing to several thousand dollars per acre-foot in the BC. Idealized water markets reduce this range by more than 86%. The CALVIN model also provides some insights on promising water transfers. Water transactions can total 790 TAF, of which 85% would satisfy urban demands.[18] Most of these transfers would occur in Southern California, mostly as part of transfers from Imperial Irrigation District to urban Southern California.

Other applications of the CALVIN model include the economic values of conjunctive use,[19] impacts of dam removal in the Hetch Hetchy system,[20] economic impacts of Bay Delta exports,[21] and long-term climate change.[22]

Limitations of the model include: (1) a perfect foresight (hydrology is known in advance); (2) data quality for some elements in the network; (3) linear-type

16. Jenkins, *supra* note 6.

17. Newlin, *supra* note 10.

18. Jenkins, *supra* note 6.

19. Manuel Pulido-Velazquez et al., *Economic Values for Conjunctive Use and Water Banking in Southern California*, 40 WATER RESOURCES 1 (2004).

20. SARAH E. NULL, RE-ASSEMBLING HETCH HETCHY: WATER SUPPLY IMPLICATIONS OF REMOVING O'SHAUGHNESSY DAM (2003), *available at* http://cee.engr.ucdavis.edu/faculty/lund/students/SarahNullThesis. pdf.

21. Tanaka, *supra* note 5.

22. STACY J. TANAKA ET AL., CLIMATE WARMING AND WATER MANAGEMENT ADAPTION FOR CALIFORNIA (2003), *available at* http://cee.engr.ucdavis.edu/faculty/lund/papers/ClimateChangeCALVIN2005. pdf.

constraints restriction; and (4) in some cases, the absence of economic values for hydropower, flood control, and recreation.[23]

III. THE LOWER COLORADO RIVER DELTA IN MEXICO AS THE CASE STUDY

A. *A Description of the Zone*

The CRD is located in the northeastern part of Baja California and extends into the northwestern part of Sonora (Fig. 4). Large scale irrigation of the CRD began in the second half of the nineteenth century.[24] Despite being the largest riparian habitat in the Sonoran Desert,[25] the CRD was harmed by the reduction of fresh water flow, the alteration of the natural flow regime, and the invasion of exotic species and animals.[26] The altered flow regimes resulted from the diversion and storage of the Colorado River for urban and agricultural water use. This reduced the extent and number of wetland habitat and wintering refuges.[27] The expanse of CRD habitat fell below 10% of its original size, from 1930 thousand acres at the beginning of the last century, to its current size of roughly 150 thousand acres.[28]

The CRD in Mexico can be divided into four ecozones, as illustrated in Figure 5.[29] The Salt Cedar/Willow/Cottonwood Zone (ecozone "A") is dominated by the invasive salt cedar (*Tamarix ramosissima*), and is the first stopover for migrating birds. In the Salt Cedar Zone (ecozone "B"), the Colorado River starts to carry runoff from Mexican agriculture.

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23. Jenkins, *supra* note 6 (detailing how these limitations on the model are recognized and addressed).

24. MICHAEL J. COHEN & CHRISTINE HENGES-JACK, MISSING WATER: THE USES AND FLOWS OF WATER IN THE COLORADO RIVER DELTA REGION (Pacific Institute 2001).

25. Edward P. Glenn et al., *Effects of Water Management on the Wetlands of the Colorado River Delta, Mexico*, 10 CONSERVATION BIOLOGY 1175 (1996).

26. Edward P. Glenn et al., *Ecology and Conservation Biology of the Colorado River Delta*, 49 J. ARID ENVIRONMENTS 281 (2001).

27. Scott A. Zengel et al., *Cienega De Santa Clara, A Remnant Wetland in the Rio Colorado Delta (Mexico): Vegetation Distribution and the Effects of Water Flow Reduction*, 4 ECOLOGICAL ENGINEERING 19 (1995).

28. LUECKE, *supra* note 1.

29. Glenn, *supra* note 25.

The Salt Grass Zone (ecozone "C") provides nesting for shorebirds while the Cattail Zone (ecozone "D") houses the Cienega de Santa Clara ("CSC"), a 4200 hectare wetland and the largest Yuma clapper rail (*Rallus longirostris yumanensis*) reserve in the CRD.[30] The CSC is also home to the desert pup fish (*Cyprinodon macularius*) and is one of the largest reserves of cattail (*Typha domingensis*).[31]

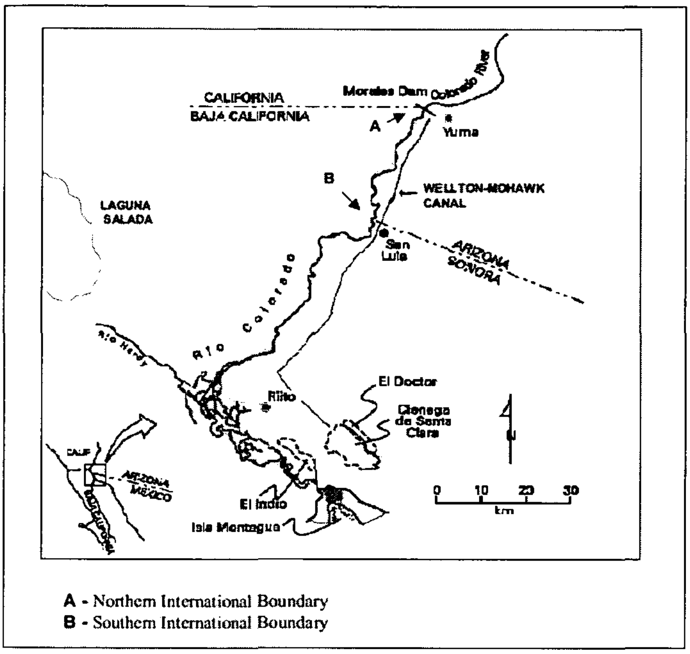

Figure 4. The Colorado River Delta.[32]

30. Osvel Hinojosa-Huerta et al., *Andrade Mesa Wetlands of the All-American Canal*, 42 NAT. RESOURCES J. 899 (2002).

31. Glenn, *supra* note 25.

32. Carlos Valdés-Casillas et al., *Information Database and Local Outreach Program for the Restoration of the Hardy River Wetlands, Lower Colorado River Delta, Baja California and Sonora, Mexico*, Instituto Tecnológico y de Estudios Superiores de Monterrey (1998).

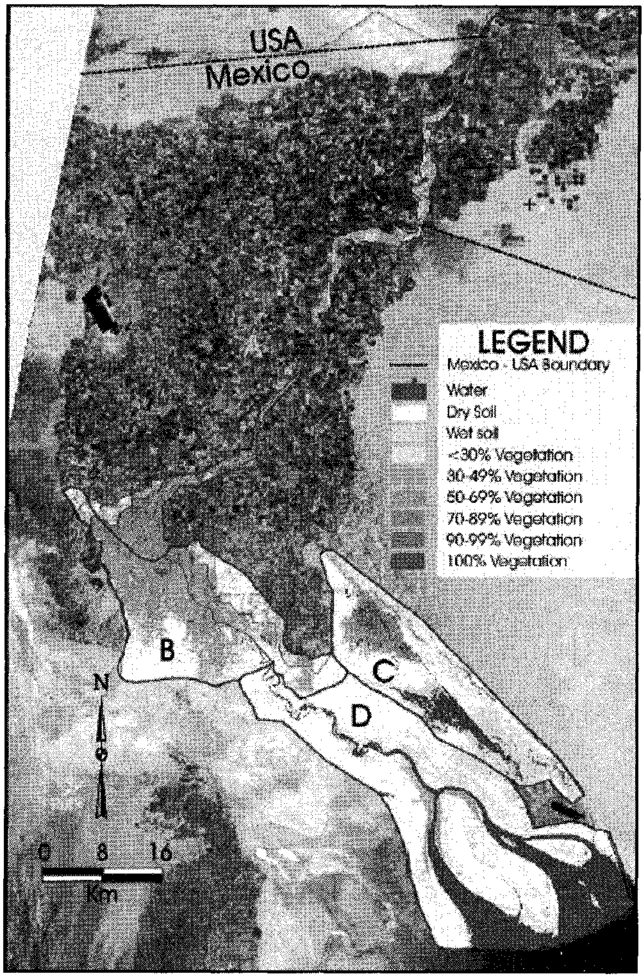

Figure 5. The ecozones of the Lower Colorado River Delta in Mexico.[33]

After construction of the Hoover and Glen Canyon dams in 1930, the CRD experienced significant water losses.[34] The bi-national U.S.-Mexico Water Treaty of 1944[35] granted Mexico 1500 TAF per year of Colorado River water from all

33. Edward P.Glenn et al., *Cienega de Santa Clara: Endangered Wetland in the Colorado River Delta, Sonora, Mexico*, 32 NAT. RESOURCES J. 817 (1992); Jennifer Pitt, *Can We Restore the Colorado River Delta?*, 49 J. ARID ENVIRONMENTS 211 (2001).

34. *Id.*

35. Treaty Regarding Utilization of the Waters of Colorado and Tijuana Rivers and of the Rio Grande, U.S.-Mex., Feb. 3, 1944, 59 Stat. 1219 [hereinafter "Water Treaty"].

U.S. sources.[36] Treaty amendments (including water quality issues and schedule of deliveries) are addressed through the International Boundary and Water Commission ("IBWC"), also established in 1944.

B. Opportunities and Concerns in the Lower Colorado River Delta

In the late 1950s, the high salinity of water deliveries to Mexico became a concern. Most of the increased salinity is attributed to the Welton-Mohawk agricultural drain in central Arizona. Because water quality was not part of the treaty, it took several rounds of negotiations to finally agree on corrective measures. Minute 242 of the IBWC established some corrective actions, including the construction of the Yuma desalting plant and a bypass canal (the "MODE"), which would redirect the saline drain more directly to the Gulf of California.[37] Water flows from the bypass canal, artesian springs, and drains from the Mexicali Valley re-established the CSC in the late 1970s, which used to be fed solely by the Colorado River before it naturally shifted its course.[38] The CSC is supported by the annual flow of about 125 TAF that passes through the MODE.[39] A threat to this flow is the operation of the Yuma desalting plant, which could substantially reduce the area of the wetland.[40]

Interest groups and researchers recommend earmarked pulse flows for the riparian corridor, as well as current flow regimes to the CSC through the MODE canal.[41] On the other hand, the riparian corridor of the CRD requires annual flows of about 32 TAF, with pulse flows of 260 TAF every four years, less than 1% of the Colorado River's average annual flow.[42] It has been argued that salinity and flow regimes determine the vegetation coverage in the CSC.[43]

Finally, another possible threat to the CRD is the lining of the All American Canal ("AAC") in California. Aparicio and Hidalgo mention previous research estimates[44] that concluded lining the first fifty miles of the AAC could reduce aquifer recharge sufficient to irrigate between 42,000 and 80,000 acres in the

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36. Norris C. Hundley, *Las Aguas Divididas: Un Siglo de Controversia Entre México y Estados Unidos*, Universidad Autónoma de Baja California (2000).

37. International Boundary and Water Commission, Permanent and Definitive Solution to the International Problem of Salinity of the Colorado River, U.S.-Mex., Aug. 30, 1973, 12 I.L.M. 1105.

38. Glenn, *supra* note 33.

39. Michael J. Cohen et al., *A Preliminary Water Balance for the Colorado River Delta 1992-1998*, 49 J. ARID ENVIRONMENTS 35 (2001).

40. Glenn, *supra* note 33.

41. *See e.g.*, LUECKE, *supra* note 1; *see also* Pitt, *supra* note 33.

42. LUECKE, *supra* note 1; Pitt, *supra* note 33.

43. Zengel, *supra* note 27; Glenn et al., *Growth Rates, Salt Tolerance and Water Use Characteristics of Native and Invasive Riparian Plants from the Delta of the Colorado River, Mexico*, 40 J. ARID ENVIRONMENTS 281 (1998).

44. Javier Aparicio & Jorge Hidalgo, *Water Resources Management at the Mexican Borders*, 29 WATER INT'L 362 (2004).

Mexicali Valley, with an estimated crop production drop of 9%. Navarro[45] notes that the current groundwater recharge from the AAC could be as high as eighty TAF per year, and that lining the AAC would raise groundwater salinity levels from 2164 to 2445 ppm in twenty years. Hinojosa-Huerta also argues that lining the AAC may prevent water flow for the Andrade Mesa Wetlands, degrading a high quality bird habitat.[46]

The CRD is an excellent location for formal integrated analysis for several reasons. First, the CRD is ecologically important since it is a zone within the Biosphere Reserve of the Gulf of California and the Colorado River Delta.[47] This reserve became official in 1993, and was included as part of the National Program for Protected Zones of 1995-2000. Second, the zone was recognized as part of the Western Hemisphere Shorebird Reserve Network in 1992, and has been listed as a Ramsar (convention) site since 1996.[48] Third, the 1944 Water Treaty allows setting a lower bound for water availability that makes this zone unique compared to other agricultural zones in Mexico. Fourth, water markets in the CRD zone are well developed relative to other zones in Mexico.[49] Fifth, there are an increasing number of organizations and individuals advocating conservation in the CRD.[50]

IV. APPLYING CALVIN TO THE LOWER COLORADO RIVER DELTA

A. *CALVIN Region 6*

The CALVIN model can be applied to the CRD in ways compatible to its application to California. A group of researchers from the University of California, Davis, and the Universidad Autónoma de Baja California ("UABC") are developing databases for a Region 6 in CALVIN that would include the CRD. This regional model includes the cities of Mexicali, Tecate, Tijuana, Rosarito, Ensenada, and San Luis Rio Colorado in Sonora, Mexico. Agricultural regions in San Luis Rio Colorado, Mexicali, Tecate, and the Valle de Guadalupe

45. J. Navarro et al., *All American Channel Concrete Living Impact on Distrito de Riego 014, Colorado*, *in* PROCEEDINGS, FIRST INTERNATIONAL SYMPOSIUM ON TRANSBOUNDARY WATERS MANAGEMENT, AVANCES EN HIDRÁULICA (A. Aldama et al. eds., 2002).

46. Hinojosa-Huetra, *supra* note 30.

47. *Borrador del Programa de Conservación y Manejo de la Reserva de la Biosfera Alto Golfo de California y Delta del Río Colorado* (2004), *available at* http://www.conanp.gob.mx/anp/consulta.php.

48. Daniel W. Anderson et al., *Migratory Bird Conservation and Ecological Health on the Colorado River Delta Region*, *in* MANAGING FOR HEALTHY ECOSYSTEMS 1091 (Dave Rapport et al. eds., 2003).

49. Wim H. Kloezen, *Water Markets between Mexican Water User Associations*, 1 WATER POLICY 437 (1998); Robert R. Hearne & José L. Trava, *Water Markets in Mexico: Opportunities and Constraints*, ENVIRONMENTAL ECONOMICS PROGRAMME DISCUSSION PAPER 97-01 (1997); Robert R. Hearne, *Opportunities and Constraints to Improved Water Markets in Mexico*, *in* MARKETS FOR WATER: POTENTIAL AND PERFORMANCE (K. William Easter et al. eds., 1998).

50. José Marcos & Steve Cornelius, *Mapping the Organization Landscape in the Colorado River Delta: the Big Picture on Binational Collaboration*, 3 SOUTHWEST HYDROLOGY 22 (2004).

in Ensenada are under consideration (Fig. 6). At least 80% of the state population is included in these urban demand areas. Agriculture is mostly concentrated in both the Mexicali Valley and in San Luis Rio Colorado in Sonora. The Morelos diversion dam in Mexico services 453,515 acres in Mexicali, and 67,952 acres in San Luis Rio Colorado ("SLRC").[51]

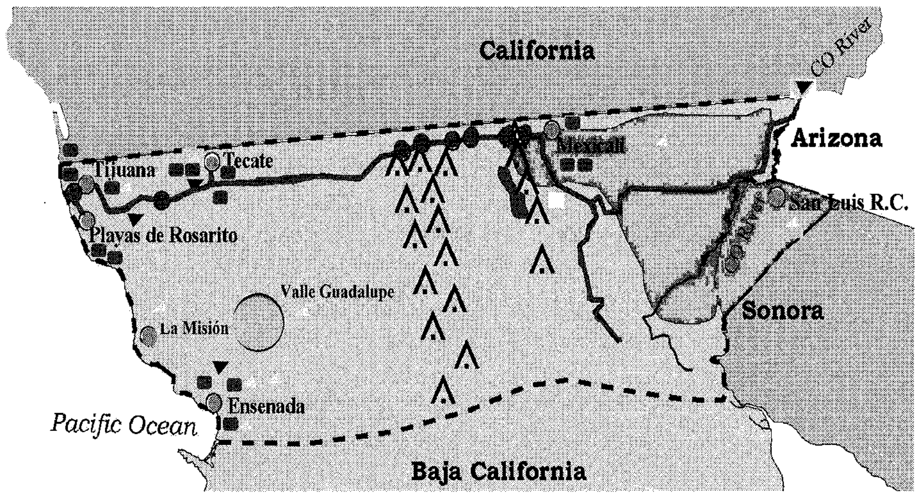

Figure 6. Region covered by CALVIN

The schematic for Region 6 in CALVIN includes reservoirs, groundwater, aqueducts, pumping stations, canals, urban demand nodes, and agricultural demand nodes. It also considers the CSC and the mouth of the Colorado River as environmental demands with minimum flow requirements.

B. *Research Issues to be Addressed Using the CALVIN Model*

CALVIN Region 6 is intended to model current and past water management issues. One of the main issues to be addressed is the economic effect of dedicated flows for the CRD restoration in terms of opportunity costs for both urban and agricultural issues. Water transfers for these dedicated water flows could be also incorporated into the CALVIN model, including scenarios from previous studies.[52] This would provide an additional quantitative tool for water management in the CRD. Another issue to be modeled with CALVIN Region 6 is the estimation of water scarcity in the CRD of Mexico and its corresponding value resulting from lining the AAC.

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51. Aparicio & Hidalgo, *supra* note 44.

52. *See e.g.* Peter Culp, *Feasibility of Purchase and Transfer of Water for Instream Flow in the Colorado River Delta, Mexico* (University of Arizona, 2000).

On the west side of Region 6, where urban water demand is greatest, it is possible to model the economic effects of increased conveyance capacity via the current Rio Colorado-Tijuana aqueduct. The model could even include a new aqueduct with a potential connection from Tijuana to San Diego, or examine the economic effects from joint water management and/or sharing between these two cities.[53]

On the other hand, studies have examined the possibility of water reuse for aquifer recharge and crop irrigation in the municipality of Ensenada.[54] CALVIN can be used for this water management issue to estimate economic gains from water reuse and decreased groundwater pumping costs. The economic viability of desalination as a water supply alternative for Ensenada and other coastal areas in Region 6 could be also studied using CALVIN. Finally, since the CALVIN model of Baja California would be compatible with the CALVIN model of California, it would be also possible to combine these two models to study various transboundary problems and opportunities.

Field data includes Colorado River inflows, surface inflows for Arroyo Seco, the Tijuana River, and the Tecate River. Groundwater inflows to aquifers such as the Mesa Arenosa in SLRC, Mexicali, Tecate, Tijuana/Alamar, La Mision, Guadalupe, Maneadero, and Ensenada will be also collected. Potable water and wastewater treatment capacities, conveyance capacities, and existing physical connection between network elements are also part of the CALVIN databases. Water demand data for both urban and agricultural regions is needed to estimate water scarcity costs. Agricultural information requires farm data on crop acreages, crop yield, water use, labor use per crop, wages, off-farm labor opportunities, pumping costs, and historical operating rules. Estimation of urban scarcity costs requires quantities and prices of water use by sector (domestic and/or industrial), and estimates of price elasticity of demand.

CALVIN results go beyond simple cost-benefit analysis or net present value project evaluation. Modeling using CALVIN takes into account the economic value of water for different users based on water scarcity and supply costs. Based on these factors, CALVIN can identify promising management activities from a broad array of options such as additional conveyance capacity, water reuse and desalination capacity, deregulation, water markets, and opportunity costs for water users under different optimized scenarios.

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53. *See* Barbara R. Bradley & Emilio de la Fuente, *Water Without Borders: A Look at Water Sharing in the San Diego-Tijuana Region*, *in* THE U.S.-MEXICAN BORDER ENVIRONMENT: BINATIONAL WATER MANAGEMENT PLANNING 247 (Suzanne Michel ed., 2003).

54. *See* Leopoldo Mendoza-Espinosa et al., *Quality Assessment of Reclaimed Water for Its Possible Use for Crop Irrigation and Aquifer Recharge in Ensenada, Baja California, Mexico*, 50 WATER SCIENCE & TECHNOLOGY 285 (2004).

V. CONCLUSION

The restoration of the Colorado River Delta will involve a variety of economic, legal, engineering, and hydrologic issues in a complex and multi-state, multi-national context. The development of a quantitative understanding of this issue will at least help us identify important unfilled knowledge gaps. When placed in a modeling framework such as CALVIN, quantitative understanding can be a venue for experimentation to help understand the possibilities, opportunities, limits, and costs of various alternatives. We look forward to presenting results of this exercise, and hopefully some successes as our bi-national team proceeds.