Transboundary Water Management at PdN: Thirty years of groundwater evolution with challenges and opportunities towards a binational planning for a holistic sustainable development

by

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Abstract

The border region between Mexico and the United States is one of the most populated areas on the world with close to 12 million people. All major watersheds at this border region are transboundary in nature where both, surface and subsurface water resources are shared by these two nations. Groundwater is the main water resource at the Cd. Juarez, Chih.-El Paso, TX-Las Cruces, NM (The Paso del Norte Region-PdN), where quantity and quality are still main issues to address in order to understand the hydrodynamics of the system and reach a holistic sustainable development of water resources for the region. While regional development and urban expansion have aggressive ongoing agendas along the border region on both countries, there is a need of a transboundary plan for a binational groundwater management in order to achieve a common ground to prevent future disagreements and water conflicts at the PdN.

Introduction

The border region between Mexico and the United States is one of the most populated areas on the world with close to 12 million people. All major watersheds at this border region are transboundary in nature where both, surface and subsurface water resources are shared by these two nations. While official efforts are on its way to reach the goal of intelligent use of these shared water resources, there is also the known fact that a thorough binational understanding on the system is needed in order to reach a proper Transboundary Water Management of these water resources. Moreover, we also need to understand and evaluate the impacts that climate change

will have on the surface and groundwater resources of the region since all climate change models for this region predict a dryer and sparser rainfall pattern, where punctual torrential rains will be a common form of precipitation, affecting recharge and increasing hydrometeorological risks. Despite the fact that surface water resources have already put in place a plan to explore a suitable binational management, groundwater is still a topic of discussion and negotiation between these two nations. Furthermore, groundwater is the main water resource at the Cd. Juarez, Chih.-El Paso, TX-Las Cruces, NM (The Paso del Norte Region-PdN), where quantity and quality are still main issues to address in order to reach a holistic sustainable development for the region. While regional development and urban expansion have aggressive ongoing agendas on both countries, there is currently a need of a transboundary plan for a binational groundwater management. In this paper, we will address the historical evolution of groundwater piezometric levels within three major regional transboundary watersheds: the Mimbres/Los Muertos region; the Mesilla/Conejos-Medanos region, and finally; the Hueco Bolson region. We will address the dynamic evolution of groundwater flow regimes and groundwater quality at these areas and evaluate the different challenges and opportunities towards a binational understanding on the system, while suggesting different alternatives that could give technical support and background towards a future binational agenda for Transboundary Water Management of these regional aquifers.

Water, People and Areas of Opportunity for Sustainability

The PdN region has been one of the most dynamic regions along both countries in regards to border crossings of people and exchange of products. These actions have determined changes in border environment quality at PdN since the demand for natural resources, such as water and unplanned change in land use, have negatively impacted the availability of these assets. In

regards to groundwater, the natural trend of punctual aquifer depletion in this region is a known factor driven by the increase demand for the resource due to population growth and the expansion of urban infrastructure, mainly in the Ciudad Juarez, Chih-El Paso, TX Region. Nonetheless, there are areas of opportunity for this region that need to be explored to develop strategic planning for water resources and more emphasis should be given to the sustainability of groundwater resources as one of the potential issues to prevent disputes and distorted focus to the problem solving binational water agenda for the PdN region.

Demographics and Challenges towards a Sustainable Water Resource Management-PdN.

It has been well documented the issue on population expansion and demographics on the border line and its potential causes and driven forces, (Hurd et al., 2006; Ganster, et al.,2000; Peach and Williams, 2000). As the trend of population increases and urban expansion keeps growing on the PdN region, the need and demands for water resources will necessarily increase as well. Since the efforts to develop plans for binational water management and improvements on water use efficiencies are timidly considered to be in place by the water agencies of both national, these water resources will be exposed to a continuous depletion. This is proven by the temporal evolution of groundwater levels on the PdN region, as shown in figure 1. The binational corridor is located within the Hueco Bolson, main reservoir of groundwater for the area, which is geospatially shared by the two nations while water management policies are different and the criteria for pumping water on this region has not yet been coordinated by both countries. The evolution of groundwater levels are shown on the graphics on the left side of figure 1 where some of the reference wells on both sides of the border line show a continuous depletion on their piezometric water levels throughout time from 1940 till approximately 1995. In addition, cones of depression located at the downtown areas of both cities shown on the map of the same figure

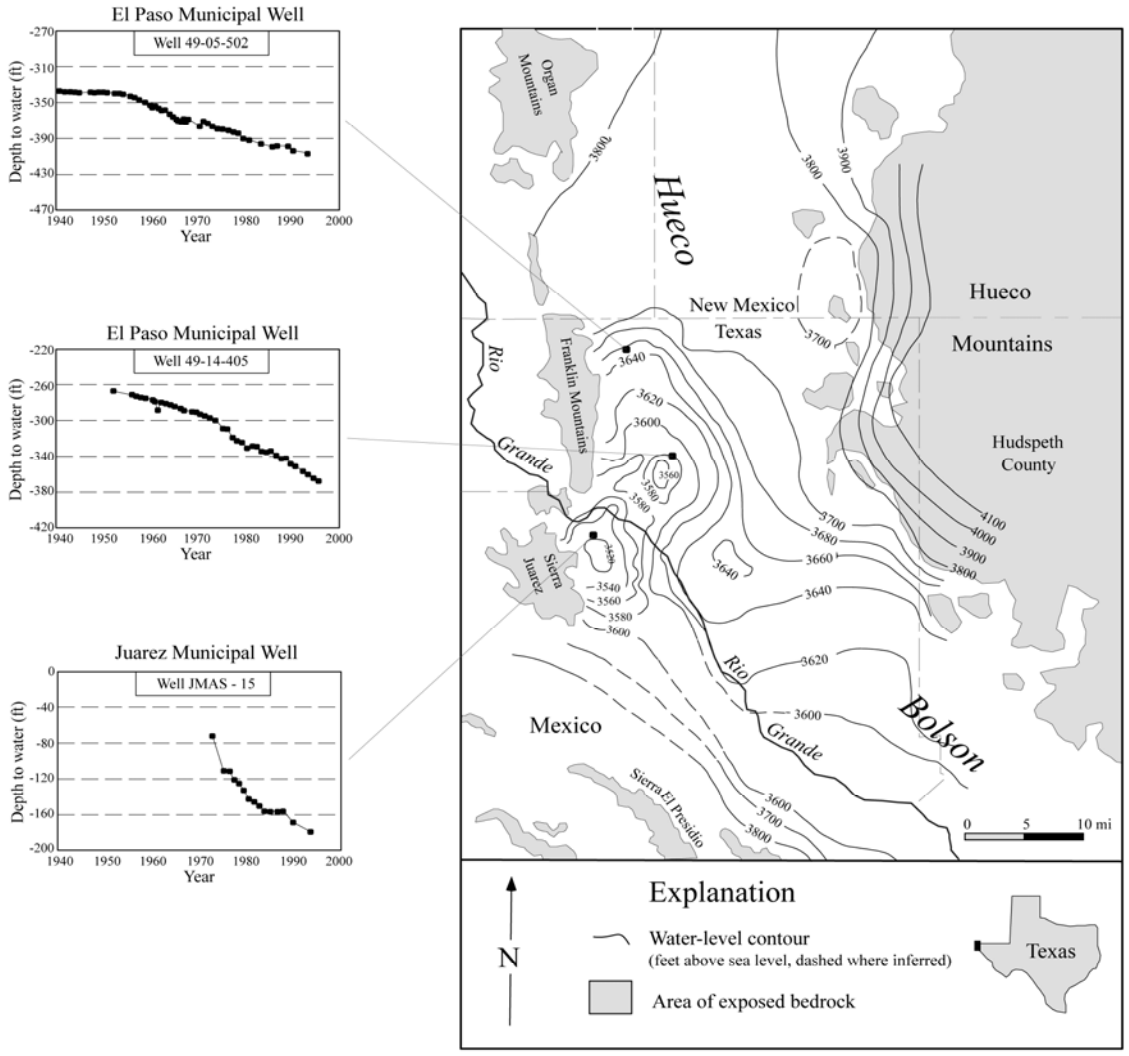

Figure 1. Groundwater level contour evolution at transboundary PdN (Source: Hibbs et al., 2003)

are some of the most relevant hydrogeologic phenomena where punctual depletions of groundwater levels are present at heavily pumped areas driven the groundwater flow towards these regions of cones of depressions on both sides of the border line. This also has implied the fact that groundwater quality has deteriorated throughout time while manifesting increases on the Total Dissolved Solids (TDS) concentrations at this transboundary region. Furthermore, this

could represent a potential health issue and the need to explore a more robust agenda on economic investments to accomplish permissible groundwater quality in order to provide treatment to these pumped waters in order to provide the required volumes to satisfy water demands at the region.

Transboundary Academic Agenda on Water Resources Research at PdN.

Scholars and experts on water resources at the PdN region have an aggressive agenda for evaluating the different transboundary scenarios in regards to availability of groundwater and to evaluate sustainable strategies for an intelligent use of water resources at the region, (Silva-Hidalgo et al., 2009; Eastoe et al., 2008; Granados-Olivas et al., 2008; Hawley and Granados-Olivas, 2008; Hibbs et al., 2008; Creel et al., 2006; Granados et al., 2006; Hurd et al., 2006). Its location, geologic formation and hydrodynamics are considered on different research efforts guided by a common endeavor to understand the hydrogeologic phenomena while applying a holistic approach to the research questions evaluated on these studies.

Physical Characterization of Transboundary Watersheds along the PdN

One of the major tasks in regards to transboundary groundwater resources at the PdN is the physical characterization of aquifer extension containing saturated deposits which will host the available groundwater for the region. Most of these "packages" of saturated sedimentary deposits product of thousands of years of geomorphologic evolution have a transboundary geospatial extension and they require the thorough understanding on their physical characteristics. Presently, the existing state of knowledge for the aquifer formations at the PdN has only half of the picture taken since the methodical application of geological information which integrates the basin-fill arrangement and its relations to groundwater availability, is still a task that has to be taken into account. For example, groundwater flow models developed on recent years for the

PdN border region have an unexplored potential since these efforts on groundwater modeling have not yet taken into consideration the integration of existing subsurface hydrogeological information that could help on the enhancement of the current available evaluation of transbounday groundwater dynamics, (Hawley et al., 2009; Hawley et al., 2000). Furthermore, descriptions of the systems have not yet been completed by the Mexican side of these transboundary watersheds. This deficiency could be eliminated in the near future while applying a methodological procedure towards a long term research agenda managed by the water agencies responsible for water administration, integrating the ongoing agenda of existing binational academic efforts. Moreover; most hydrogeologic and geohydrologic official investigations on groundwater resources along the border line have the "white map" syndrome where geospatial extension of geomorphic units are "cut" at the boundary of both countries; whereas, other projects have only provided exchanges of existing information while leaving behind the additional effort to integrate at the border line such geospatial information in a common binational geodatabase, (Creel et al., 2006; Granados-Olivas et al., 2006; Hibbs, et al., 1997)

Water Availability at the PdN and Neighboring Areas: The Hueco Bolson; The Conejos Medanos/Mesilla Bolson and The Mimbres/Los Muertos Basin

While it is known that one of the most important developing areas along the border region is located within the El Paso, TX-Las Cruces, NM-Cd. Juarez, Chih., metropolis, its only logical to take into consideration the original concern of present and future demands for water resources on this region. There are different projections in regards to water demands for the PdN region among those some short term estimates consider the increase of water demands accordingly with past evolution of registered consumption of water by different users along the watershed. Hence, it is estimated that demands of water by 2030 will increase along with population growth and

urban expansion at the PdN region and that environmental impacts could be reflected on groundwater quality deterioration as well as depletion of groundwater levels. This brings into account the increase consumption of energy due to electricity required to keep pumping from deeper settings on the aquifers where the well fields providing the demanded water are located. Also, pumping groundwater from deeper locations on the wells could impact family budgets and the local economy in general, despite of the environmental impacts while evaluating additions that these high consumptions of energy might add into the general equation of climate change and global warming. Nonetheless, these high consumption rates are well located on the urban areas of the PdN as shown on figure 1, where cones of depression generated due to heavy pumping are practically punctual depressions as compared to the complete extension of the aquifer formation. In other words, the deterioration of groundwater quality and the depletion of the water table are located at a ¨small¨ area as compared to the total extension of the aquifer formations. Unfortunately, the major urban expansion where main infrastructure and the highest demands for water are located is precisely at this ¨small¨ area treating the quality of life for these citizens located at this binational community. Eventually, if all things keep evolving as they have been doing on the recent past, the deterioration of the groundwater quality would get worse and the depletion of the groundwater table will get deeper extending the geographical expansion of the identified cones of depression to a broader area as compared with present evolution. This will force the need for more infrastructure to conduct water from the other neighboring aquifer formations increasing the prices of water services. Furthermore, this expansion of the well fields onto rural areas, which have implied the predominant economic activity based on agriculture and livestock, will have a conflict on the water markets arena since the ag community also have their own need for water and land. This type of scenario is one that is not far from reality since a

similar case study has reflected this conflict of interests on the Conejos-Medanos Basin, west side of the Sierra de Juarez (Fig. 1), where recent change on land use has forced cattlemen out from their land in order to make space to a major groundwater project, the Conejos-Medanos Groundwater Project, that will provide water and partially satisfy demands for the city of Juarez. However, it is known that available groundwater resources at the PdN and surrounding areas are vast and have great potential for the region including regions of the main aquifer system found at the PdN, the Hueco Bolson and the adjacent aquifer formations of the Mesilla-Conejos Medanos Aquifer and the Mimbres-Los Muertos Basin (Hawley et al., 2009; Hawley and Granados-Olivas, 2008; Eastoe et al., 2008; Hibbs et al., 2008; Creel et al., 2006; Granados-Olivas et al., 2006; Hibbs et al., 2003; Hawley et al., 2000; Hibbs et al., 1997). Nonetheless, these available groundwater resources at the new Conejos-Medanos well field are questionable since there are no complete studies that can prove that the extension of the aquifer formations are capable of sustaining pumping without generating new irreversible cones of depression or even worst that groundwater quality will not have appropriate quality standards to meet established parameters in order to provide this water to the people at this area without repeating the present story of the Hueco Bolson. Furthermore, is unquestionable that an important major project, such as the one been described in this case study, should have a major plan of evaluation and monitoring to keep track of eventual changes that the aquifer might have due to heavy pumping and to plan a strategy to reach sustainability of these important water resources. However, the actual budget that was assigned to develop this infrastructure in the Conejos-Medanos Groundwater Project did not included any economic resources to establish a research team of experts to begin a research agenda on the system and keep track on these potential changes, loosing this great opportunity to manage this aquifer in a sustainable way with a holistic approach.

Climate Change and its Impacts on Transboundary Accessibility to Water Resources

Global warming and climate change are two of the major factors influencing the availability of both surface water and to a long term groundwater, since climate change predictions and modeling for this border region located at the Chihuahuan Desert Ecosystem, estimate a dryer region with intense torrential precipitation unevenly distributed and unpredictable. This could bring changes to the hydrologic phenomena occurring on the region where runoff will be subject to these immediate changes due to potential reduction of flow product of the sparse precipitation patterns. On the other hand, intense punctual precipitation fallen as torrential rains could increase runoff at places where precipitation occurs reducing time of concentration due to heavy rainfall at points where it occurs within the watersheds which could increases at the same time the risk for potential flooding and hydrometeorological hazards (Rojas-Villalobos, et al., 2008; Granados-Olivas et al., 2007). In regards to groundwater and the potential impacts climate change might have toward a sustainable development for the region, the challenge to measure progress toward the accomplishment of this goal is even greater. It is well understood that time of residence of groundwater located within the confining saturated strata found at local aquifers, has a broad range spectrum on the time scale and it also has a geospatial component. For example, studies on groundwater time of residence at the PdN while evaluating isotopic signature on tapped groundwater resources demonstrated that the Hueco Bolson had an average time of residence of approximately 45 years at the piedmont slopes found close to hills on the Sierra de Juarez, whereas time of residence on the plains of the same aquifer formation where on the range of more than 3000 years, (Eastoe et al., 2008; Hibbs et al., 2003). Also, groundwater quality could be related to geomorphic features and to the potential recharge these regions may have. For example, wells located close to recharge areas, such as arroyos and fracture traces

located at these piedmont slopes within the Hueco Bolson have different TDS concentrations providing a better groundwater quality (Granados-Olivas, et al., 2005; Granados-Olivas, et al., 2003). Hence, if climate change modifies precipitation patterns and the types of torrential rains falling at these regions, a change in availability and groundwater quality could be expected, specifically within these highly dynamic regions with a special hydrogeology in regards to groundwater flow patterns and recharge potentials. Nonetheless, all these hydrogeologic scenarios have to be studied in more detail in order to advance and have progress toward sustainability since these are dynamic and long term investments which need to be considered and approach with a binational focus and agreements. For example, a plan for a binational research center on water resources needs to be address on the near future for the PdN region and its surroundings. This will require the understanding and clear concurrence by the two nations in regards to long term monitoring and exchange of data, as well as, the definition of a common ground to determine logistics for this potential binational endeavor, where issues such as: units, definition of terms, scales of analysis, methodologies, language and most importantly, a thorough understanding of the agreements and limitations of such an effort have to be address, all of which need to be based on the application of the recommended actions based on scientific research results to achieve sustainability for groundwater uses at the borderlands.

Review of Mexican Water Law and its implications on a Transboundary Environment

Mexico has a long tradition on developing different kinds of laws that regulate the application of justice and the preservation of human rights. In fact, Mexico´s constitution is one set of rules and agreements that regulates the most basic and important human rights for all citizens on this country and these laws are the main driver for achieving a fair and just country. In regards to water, there are also well developed efforts to establish how Mexican citizens have the right to

water resources on the country and these bylaws are enforced by special water agencies such as the National Commission for Water (CNA by its Spanish acronym). This national water agency is responsible for the sustainability of water resources on all the country and it is regulated by the Law for National Waters which allows all citizens to know their water rights (LAN by its Spanish acronym: http://www.diputados.gob.mx/LeyesBiblio/pdf/16.pdf). Nonetheless, despite the fact that it might be seen as an advantage to have single agencies enforcing water regulation for the complete country, it is also known that contradictions are in place while trying to achieve the sustainability argument while trying to find solutions to comply with socio-economic and environmental issues while enforcing a disconnected water law from the reality happening on the watersheds. For example, in regards to sustainability of groundwater resources on the rural areas, Mexico initiated an effort to regulate all groundwater rights in the country and established on the late 1990´s an agenda requiring all owners of ag-water wells to attend local offices of CNA to register what the people believed was their water right. Furthermore, in the case of the ag-wells at the Mexican side of the Mimbres-Los Muertos Basin, these water wells had no previous permits and some had been establish since early 1960 as part of an official effort to populate these northern regions of Mexico. With this program, an additional effort was taken on those times which included a monitoring of piezometric levels, establishing an agenda of two specific dates during the year (Winter and Summer measurements) to monitor groundwater table evolution. However, this program stopped in early 1980´s due to budget restrictions and it was recently reestablish in 2009 as part of a onetime effort to redefine the groundwater table evolution at the watershed. During this period of time with close to 30 years of discontinuity of the groundwater monitoring agenda and law enforcement, many new wells were drilled on this watershed affecting on some areas of the basin with significant depletion of the groundwater

level, while in other areas of the same aquifer, no significant impacts where detected preserving the 1980´s groundwater levels (Granados, 2000, Granados and Monger, 1999). However, despite the obvious incomplete knowledge on the aquifer formation and evolution on this area, the water authority declared a "no more drillings zone" but without the actual law enforcement or with a strategic plan to prevent new drillings or even worst, with a scientific foundation strategy that could help on taking decisions based on research results generated at a research center for studies of groundwater resources which, at the same time could have been administered by regional scholars and academics from leader institutions on the region ensuring long term strategies and decision making. This disconnected plan has brought into play recent unstable conditions and social unconformities on the area since the Chihuahua state offices of CNA have taken an aggressive approach to the groundwater problem on the Los Muertos Basin region, and in many other areas on the state. This aggressive approach has been taken into action and has been enforced on the area while cancelling water well permits and sealing many of these ag-wells leaving the local farming community irritated and hopeless while the authorities take an inflexible approach with the argument of "finding" on these properties an unjustified drilled water well, instead of having a problem solving approach that could help on updating the information on water wells located at the basin. This wrong approach taken by CNA to this problem is mistaken since the knowledge on groundwater budgets for the area which could be used to justify these actions, is incomplete or erroneous since many of the hydrologic variables that could produce a water budget for the basin are wrong, out of date or even worst "estimated" and not measured. For example, recharge in the basin is an important variable to take into consideration in order to accomplish thorough groundwater volume estimation. However, this is one of the huge unknowns for the region leaving the option for a real groundwater budget

incomplete; furthermore, another of the important variables for a real estimate on the availability of groundwater resources on the area is the volume of extraction from the local aquifer. This number takes into consideration the measured pumped volume from each of the existing wells on the area adding all these and generating an estimated total volume of extraction. Since not all these wells are registered and most of the registered wells do not have a flow meter integrated on them as part of the well design, CNA will calculate this available volume of groundwater for the basin based on the allowable groundwater permits which are only volumes printed on paper without the actual measurement taken on the field for these water wells, producing misleading information and eliminating the possibility for a change in policy to reach a successful groundwater sustainability for the area. Furthermore, these actions have impacted the economy and way of living of complete families with the resulting abandonment of their properties while immigrating to other places on the basin, to the city or worst crossing the border into the U.S. looking for a better quality of life.

So, are we ready for a Binational Groundwater Treaty?

No. Since Mexico still need to define its strategic plans in regards to sustainable management on groundwater resources as well as a scientific knowledge of the aquifer formations is still in the course of its development, no official authority responsible for the administration of water resources will have the capacity to sit on a binational round table and define its position in regards to allowable volumes of extraction on its own territory. First, there is the need to change within each of these countries, policies in regards to groundwater strategies and prioritized the need of a complete knowledge of the system in order to administer the water resources on these aquifer formations. In the case of Mexico, the water authority still needs to solve the discrepancies between water users within its own territory located along these transboundary

watersheds and redefine their strategies towards the creation of water institutions with a problem solving philosophy and not the ones been presently responsible of the administration of these water resources which are presently applying a burden of bureaucratic jargon and obstacles drowning the possible solutions to the important task of groundwater sustainability in order to solve our differences and move the border region forward towards an environmental sustainability into the 21st century.

Summary

We have discussed different issues in regards to groundwater at the PdN and neighboring basins as potential alternatives to reach a sustainable environment for the transboundary watersheds that have in common the sharing of both, surface and groundwater resources within this region. Emphasis was given to the analysis of groundwater resources and its management mostly on the Mexican side of the watershed. We have addressed different challenges the region has in order to reach a sustainable environment evaluating social, economic and environmental characteristics these transboundary watersheds have which makes them unique to study the water and environment and its relation to the border socio-economic perspective. It is important to emphasis that many of the discussed issues have their ongoing research agendas and that the results of these works will bring more light into the solving problem towards a binational agenda on water resources for the region. Issues such as binational agreements on the potential binational administrations of groundwater resources are possible, but unfortunately not in a short term since many important issues are still to be resolve mostly on the Mexican side of the watershed. Efforts should be address towards the investment of economic resources and integration of interdisciplinary teams of binational experts to work in the direction of a binational agenda to evaluate potential scenarios for a sustainable environment at the border lands.

Bibliography

Creel, Bobby J., John W. Hawley, John F. Kennedy, Alfredo Granados-Olivas, 2006. GROUNDWATER RESOURCES OF THE NEW MEXICO-TEXAS-CHIHUAHUA BORDER REGION. New Mexico Journal of Science. Vol. 44, August 2006. New Mexico Academy Of Science, 2006. ISSN: 0270-3017. Pag. 1-19.

Eastoe, C.J.; B.J. Hibbs, A. Granados-Olivas, J.F. Hogan, J. Hawley, W.R. Hutchison, 2008. Isotopes in the Hueco Bolson Aquifer Texas (USA) and Chihuahua (Mexico): Local and General Implications for Recharge Sources in Alluvial Basins. Hydrogeology Journal, Volume 16, Number 4, June 2008. Official Journal of the International Association of Hydrogeologist (IAH-AIH) Springer-Verlag. ISSN Printed Edition: 1431-2174; ISSN Electronic Edition: 1435-0157. DOI 10.1007/s10040-007-0247-0

Ganster, Paul, David Pijawka, Paul W. Rasmussen and Rick Van Schoick, 2000. Overview-Findings of Border Institute I, The U.S.-Mexican Border Environment: A Road Map to a Sustainable 2020. In SCERP Monograph Series, no.1. Edited by Paul Ganster. San Diego State University Press 2000.

Granados-Olivas, Alfredo; Erick, Sanchez-Flores; Antonio, De la Mora-Covarrubias; Servio Tulio, De la Cruz; Gerardo, Reyes-Macías; Francisco, Llera-Pacheco; Javier, Chávez; Bobby, Creel; Chris, Brown; 2008. ROADMAP OF GEOSPATIAL EDUCATION IN MEXICO. ASPRS 2008 Annual Conference Portland, Oregon ♦ April 28-May 2, 2008. ISBN 1-57083-087-8

Granados-Olivas, Alfredo, Chris Brown, Erick Sánchez-Flores, Antonio de la Mora, and Oscar Dena-Ornelas, 2007. The 3 “G’s” in Disaster Prevention: Geoinformatics, Geosciences and

Groups (People). 32nd International Symposium on Remote Sensing of Environment. "Sustainable Development Through Global Earth Observations" San Jose, Costa Rica, 25-29 Junio, 2007. ISBN:978-0-932913-12-8. Pag. 381.

Granados-Olivas, Alfredo, Chris Brown; Ms. Janet Greenlee; Bobby Creel; John Hawley; John Kennedy; Oscar Dena-Ornelas; Brian Hurd, 2006. Geographic Information Systems at the Paso del Norte Region. The Academic Accomplishments and Challenges for a Transboundary Water Resources GIS Cooperation. New Mexico Journal of Science. Vol. 44, August, 2006. New Mexico Academy Of Science, 2006. ISSN: 0270-3017. Pag 59-70.

Granados-Olivas, Alfredo**,** Barry Hibbs, Chris Eastoe, John Hawley, 2005. "Fracture Trace Analysis of Structural Geology at the Sierra de Presidio and its Relationship to Hydrogeochemistry". 2005 Annual Meeting of CEA-CREST, Arid Zone Hydrology Symposium. Cal-State University. Pasadena, California, Mayo, 2005. Abs. with programs, p. 11.

Granados-Olivas, Alfredo and Rafael Corral-Díaz, 2003. Fracture trace and alignment analysis for groundwater characterization on a non-karst arid environment in the Chihuahuan Desert, México. Hydrology of Mediterranean and Semiarid Regions. IAHS Publication no. 278/ ISSN 0144-7815/ISBN 1-901502-12-0, Pp.24-28. International Association of Hydrological Sciences, Montpellier, France, April, 2003.

Granados, A., and Monger, H.C., 1999. Remote Sensing Technology for Development Planning Along the U.S.-Mexico Border: Hydrogeology and Geomorphology *in* Herrera, E. and Mexal, J., eds. New Mexico Academy of Science 1999 Journal. Ensuring Sustainable Development of Arid Lands Trough Time, Las Cruces, N.M. Vol. 39, Nov. 1999 pp.123-137

Granados-Olivas, A., 2000. Relationships between Landforms and Hydrogeology in the Lower Casas Grandes Basin, Ascension, Chihuahua, Mexico. Unpublish Ph.D. Dissertation. New Mexico State University, Las Cruces, N.M., May, 2000, 292 p.

Hawley W., John; John F. Kennedy; Alfredo Granados-Olivas and Marquita A. Ortiz, 2009. Hydrogeologic Framework of the Binational Western Hueco Bolson-Paso del Norte Area, Texas, New Mexico, and Chihuahua: Overview and Progress Report on Digital-Model Development. WRRI Technical Completion Report No. 349. New Mexico Water Resources Research Institute. New Mexico State University. December, 2009. 45 pag.

Hawley W. John; Barry J. Hibbs; John F. Kennedy; Bobby J. Creel; Marta D. Remmenga; Molly Johnson; Monica M. Lee; Phil Dinterman, 2000. Trans-International Bounday Aquifers in Southwestern New Mexico. Technical Completion Report prepared by New Mexico Water Resources Research Institute, New Mexico State University and California State University, Los Angeles. March, 2000. 126 pages.

Hawley, John W. and Alfredo Granados-Olivas, 2008. PROGRESS REPORT ON DEVELOPMENT OF AN ANNOTED BIBLIOGRAPHY FOR TRANSBOUNDARY AQUIFER SYSTEMS OF THE MESILLA BASIN-PASO DEL NORTE AREA, NEW MEXICO, TEXAS (USA), AND CHIHUAHUA (MEX). NM Water Research Symposium, Socorro, New Mexico August, 12, 2008.

Hibbs, Barry; Bill Hutchinson; Chris Eastoe, and Alfredo Granados-Olivas; 2008. Induced Infiltration From the Rio Grande Replenishes the Hueco Bolson Aquifer – But Will It Last? Non-Renewable Ground Water Resources The Socio technological Aspects of Non-renewable Ground Water Resources: Half-empty, Half-full, Top-down, Bottom-up, and Some Paths

Forward. National Ground Water Association. 2008 Ground Water Summit March 30-April 3, Memphis, Tennessee.

Hibbs, Barry, Fred Phillips, James Hogan, Chris Eastoe, John Hawley, John Kennedy, Francisco Nuñez, Alfredo Granados and Thomas Kretzschmar, 2003. Binational Study of the Surface and Ground Water Resources of the El Paso/Juárez International Corridor. Journal of Contemporary Water Research and Education, v.125, p. 25-30. Update Water Resources, Issue Number 125 Pp.25-30. The University Council On Water Resources, June, 2003. Southern Illinois University, Carbondale, Illinoise

Hibbs, B., Phillips, F., Hogan, J., Eastoe, C., Hawley, J., Granados, A., and Hutchison, B., 2003, Hydrogeologic and Isotopic Study of the Groundwater Resources of the Hueco Bolson Aquifer El Paso/Juárez Area: Hydrological Science and Technology, v. 19, (1-4), p. 109-119.

Hibbs. B.J., B.J. Creel, R. Boghici, M. Hayes, J. Ashworth, A. Hanson, Z. Samani, J.F. Kennedy, P. Hann, and K. Stevens, 1997. Transboundary Aquifers of the El Paso/Ciudad Juarez/Las Cruces Region: U.S. Environmental Protection Agency, Region 6; Technical Contract Report prepared by the Texas Water Development Board and the New México Water Resources Research Institute.

HURD BRIAN, CHRIS BROWN**,** JANET GREENLEE, ALFREDO GRANADOS-OLIVAS, MARGUERITE HENDRIE, 2006. ASSESSING WATER RESOURCE VULNERABILITY FOR ARID WATERSHEDS: GIS BASED RESEARCH IN THE PASO DEL NORTE REGION. New Mexico Journal of Science. Vol. 44, August, 2006. New Mexico Academy Of Science, 2006. ISSN: 0270-3017. Pag. 203-225.

Peach James and James Williams, 2000. Population and Economic Dynamics on the U.S.-Mexican Border: Past, Present and Future. In SCERP Monograph Series, no.1. Edited by Paul Gnaster. San Diego State University Press 2000.

Rojas-Villalobos, Hugo Luis; Víctor Ezquivel-Ceballos; Alfredo Granados-Olivas; Jorge Salas-Plata; Héctor Quevedo Urias, 2008. REAL TIME ANALYSIS OF HYDROMETEOROLOGICAL RISKS AND GEOESPATIAL DISTRIBUTION OF PLUVIAL RETURN PERIODS IN A TRANSBOUNDARY WATERSHED: THE US-MEXICO PASO DEL NORTE REGION CASE STUDY. 2008 UCOWR/NIWR Annual Conference *International Water Resources: Challenges for the 21st Century.* Durham, North Carolina, July, 21-22, 2008.

Silva-Hidalgo, H.; Martín-Domínguez, I.R.; Alarcón-Herrera, M.T. y Granados-Olivas, A. Mathematical Modelling for the Integrated Management of Water Resources in Hydrological Basins. *Water Resources Management*. Vol.23. No.4. pp721-730 (2009). ISSN: 0920-4741.