WATERSHED ANALYSIS OF RUNOFF AND EROSION POTENTIAL ON SANTA CRUZ WATERSHED (ARIZONA, USA AND SONORA, MEXICO): IMPACT OF CLIMATE AND LAND COVER CHANGES

Y. Yuan and W. Nie[2]

ABSTRACT

The Southwest Ecosystem Service Program (SwESP) is part of the US Environmental Protection Agency (EPA)'s newly undertaken Ecological Service Research Program (ESRP) to examine the variety of ways in which landscapes including crop lands, conservation areas, wetlands, lakes, and streams contribute to wildlife and human well-being. The goal of the SwESP is particularly to examine the landscape of the Southwest area to quantify the current magnitude of those contributions from the landscape, and to examine how ecosystem services in the Southwest could change over the next decade. Given the growing demand for water due to population growth and potentially decreased snow and precipitation due to climate change, water availability has become a dominant issue in arid and semi-arid ecosystems. As a part of this effort, quantifying past climate changes and how these changes affect quantity and quality is very important. Thus, the objectives of this study are to examine historical climate and streamflow changes and estimate its impact on future available water resources and management. To achieve the overall objective of this study, climate data, USGS daily stream flow and peak discharge were analyzed from a southwestern U.S. watershed. It was found that the annual precipitation has a decreasing trend from 1960 to 2008. While the monthly average minimum temperature has a tendency of increasing, the monthly average maximum temperature does not show the same phenomena. As annual precipitation decreases, the annual stream flow has a tendency of decreasing although annual stream flow does not correspond with annual precipitation very closely. This is because the unique storm characteristics such as rainfall intensity and duration also impact the runoff generation in addition to the total amount of rainfall as demonstrated by many other studies (Critchley et al., 1991). Although the increased urban landcover (Homer et al., 2004; Fry et al., 2009) would result in increased stream flow (Franczyk and Chang 2009), the increased temperature seems override the effects of increased urban landcover. Since there is little sediment data available from the watershed, peak discharge was analyzed to provide an indication of potential soil erosion and sediment transport. The highest peak discharge is probably a result of the combination of higher intensity rainfall and increased urban landcover. Therefore, the watershed is potentially more vulnerable to flooding risk and degraded water quality due to potentially increased soil erosion and sediment transport.

KEYWORDS. Precipitation; Temperature; Stream flow; Peak discharge; Soil erosion; Watershed.

---

[2] The authors are **Yongping Yuan, ASABE Member Engineer,** Research Hydrologist, USEPA-Office of Research and Development, NERL-ESD-Landscape Ecology Branch, Las Vegas, Nevada; Wenming Nie, Student Service Contractor, USEPA-Office of Research and Development, NERL-ESD-Landscape Ecology Branch, Las Vegas, Nevada. **Corresponding author:** Yongping Yuan, USEPA-Office of Research and Development, NERL-ESD-Landscape Ecology Branch, P.O. Box 93478, 944 East Harmon Avenue, Las Vegas, NE 89119; phone: 702-798-2112; e-mail: yuan.yongping@epa.gov.

INTRODUCTION

The Southwest Ecosystem Service Program (SwESP) is part of the US Environmental Protection Agency (EPA)'s newly undertaken Ecological Service Research Program (ESRP) to examine the variety of ways in which the landscapes, including crop lands, conservation areas, wetlands, lakes, and streams contribute to wildlife and human well-being. The goal of the SwESP is particularly to examine the landscape of the Southwest area to quantify the current magnitude of those contributions from landscape, and to examine how ecosystem services in the Southwest could change over the next decade. Given the growing demand for water due to population growth and potentially decreased snow and precipitation due to climate change, water availability has become a dominant issue in arid and semi-arid ecosystems. As a part of this effort, quantifying past climate changes and how this change results in water quantity and quality change is very important.

Impacts of potential climate change on hydrology have been widely studied in recent years (U.S. Department of the Interior, 2009). Quantifying the threat posed to water resources due to climate change is particularly important for the arid and semi-arid Southwest. Studies investigating climate change impacts on hydrology and water resources can be summarized in the following three groups: 1) historical climate and hydrology; 2) projected future climate and hydrology; and 3) their impacts on environmental resources and/or ecosystem services. Assessing impacts of landuse changes on hydrology is also essential for watershed management and ecological restoration. The assessment usually includes evaluation of spatial patterns of hydrological consequences to different landuse scenarios, comparison of simulated hydrological processes to landuse changes at the watershed scale, and examination of temporal responses in channel discharge with changes in climate and landuse scenarios (Ghaffari et al., 2009; Franczyk and Chang, 2009). The objectives of this study are to examine historical climate and streamflow changes and analyze potential threats to water quality and quantity.

METHODS AND PROCEDURES

Study Site

The upper Santa Cruz watershed located in Arizona, USA and Sonora, Mexico was selected for this study (Figure 1). As shown in Figure 1, two major cities Tucson and Nogales are located in the watershed. The Santa Cruz river originates in Arizona, flows south into Sonora, Mexico, and then flows north back into southeastern Arizona, USA (Figure 1). The upper Santa Cruz watershed has an area of about 9,073 km^2, and lies between latitude 31°02′ and 32°40′ N and longitude -111°18′ to -110°20′ W. Elevations in the watershed range from 496 to 2883 m, and annual rainfall ranges from less than 200 to more than 800 mm (valley to mountain). The dominant vegetation in the upper Santa Cruz watershed is desert shrub, the proportional extent of which is over 70% (USGS, BEHI). Other vegetation types include forest, grassland/pasture, agriculture, riparian and wetland (USGS, BEHI).

Urban lands occupy over 5% of the watershed since 1992 (USGS, BEHI). The largest urban area in the watershed is Tucson where over a million people live in the metropolitan area and a half million live within the city limits. The second largest city is Nogales, Sonora, with over 300,000 people.

NOAA Climate Data Analysis

Climate information including daily values of precipitation, evaporation and minimum-maximum temperature from National Oceanic and Atmospheric Administration (NOAA) weather stations within 50 kilometers of study area was collected and analyzed. Missing records from one weather station were interpolated using the weather data from neighboring weather stations and Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly et al., 1997). The inverse distanceweighted (IDW) interpolation method was used. The detailed information on data interpolation can be found in Di Luzio et al. (2008).

Based on daily maximum/minimum temperature, the average maximum and minimum temperature for each month was calculated. Trend analysis was performed for each month. In addition, total precipitation for each year and month was calculated based on daily precipitation and trend analysis was also performed for annual precipitation.

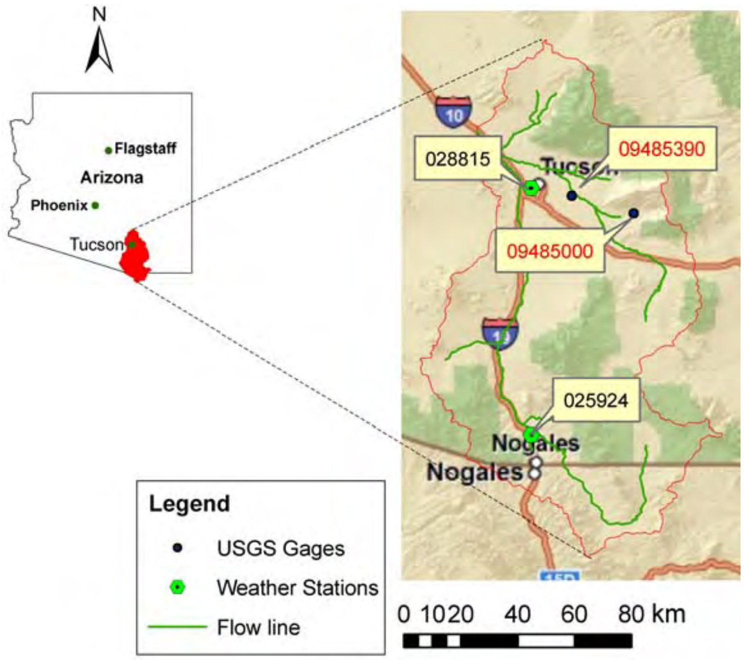

Figure 1. Location of the upper Santa Cruz River Basin (Arizona/Mexico)

<u>Stream Flow Data Analysis</u>

Monthly stream flow from USGS gauging stations located in the watershed was downloaded from the U. S. Geological Survey (USGS) National water Information System (NWIS) (.http://waterdata.usgs.gov/nwis/). It was found that there were several diversions along the main stream which impacted the flow timing and amount of several monitoring stations. Therefore, data from each monitoring station were scrutinized to select stations which data were not impacted by human alternation. Preliminary data analysis showed that there is not a single station having continuous data from 1960-2008; thus data from nearby stations were used to fill the missing years in order to have a long-term stream flow record. Since data were missing from 1974 to 1987 for station 09485000, the observed data at station 09485390 from 1976 to 1982 were used. Annual runoff was expressed as mm in order to compare with annual rainfall.

<u>Peak Discharge and Indication to Soil Erosion and Sediment</u>

Sediment data from USGS gauging stations located in the watershed was investigated and it was found that little sediment data was available in the watershed. Thus, peak flow data at the USGS Gauging station 09485000 was downloaded and analyzed to provide an indication of the erosion potential and sediment information of the watershed.

RESULTS AND DISCUSSION

Weather data

Annual average precipitation (1960-2008) ranges from 228-mm to 862-mm, depending on the location of the weather station. Generally, the precipitation is higher at higher elevations. Annual average precipitation from two weather stations (025924 and 028815) is displayed in Figure 2. The location of the weather stations is displayed in Figure 1. The annual average for station 025924 is 449-mm and the annual average for station 028815 is 297-mm. The elevation for station 025924 is 1055-m (3461-ft) above sea level and the elevation for station 028815 is 742-m (2435-ft) above sea level. For the period of 1960 to 2008, annual precipitation has a tendency of decreasing at both stations as shown in Figure 2. The annual precipitation was decreased by less than 1-mm (Figure 2).

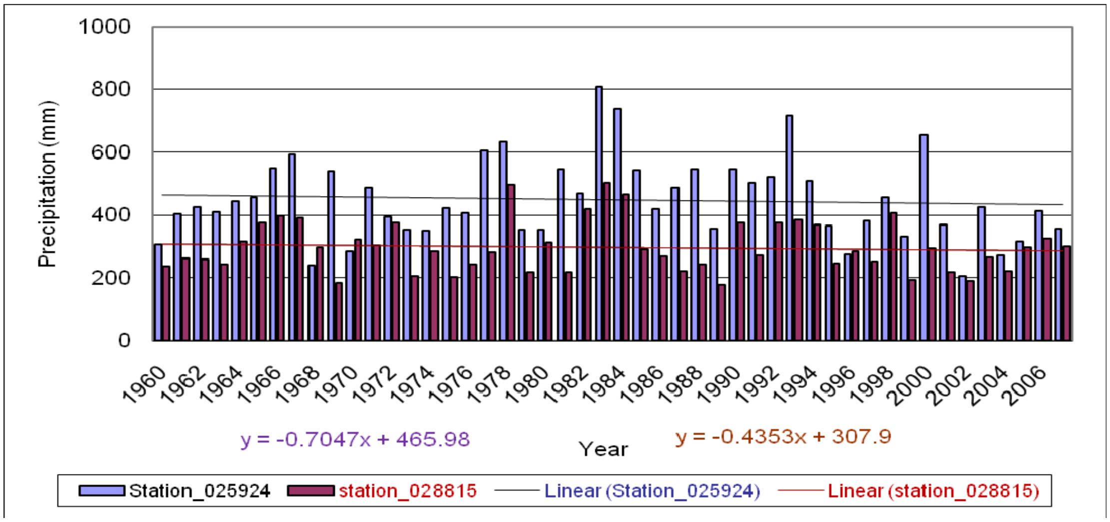

Figure 2. Annual rainfall and their trend lines at two weather stations (025924 and 028815)

Monthly Maximum and Minimum Temperature

At station 025924, the monthly average maximum temperature has a tendency of increasing for each month as shown in table 1. The monthly average minimum temperature also has a tendency of increasing for each month except December (table 1). However, at station 028815, the monthly average maximum temperature has a tendency of decreasing for each month except for May and June (table 1). The monthly average minimum temperature also has a tendency of increasing for each month (table 1). Figure 3 shows the data for January at both stations. In addition, both maximum and minimum temperatures are lower at higher elevation (Figure 3)

Stream Flow at USGS Gauge Station (09485000 and 09485390)

Annual stream flow from gauging stations 09485000 (1960-1974 and 1987-2009) and 09485390 (1976-1982) are displayed in Figure 4. Although data from the years of 1975, and 1983-1986 were missing, the annual runoff has a tendency of decreasing. Annual runoff corresponds with annual precipitation for some years (1993, 1995 and 1998) and not in other years (1994 and 2000) (Figures 2 and 4). The rainfall in 1994 and 2000 is higher than 1995 and 1998, but the runoff in 1994 and 2000 is lower than that in 1995 and 1998. As demonstrated by many other studies, the unique storm characteristics such as rainfall intensity and duration impact the runoff generation in addition to the total amount of rainfall (Critchley et al., 1991). Other factors such as landcover and temperature also impact the runoff generation. Urban landuse increased from 1992 to 2001 and again from 2001 to 2006 (Homer et al., 2004; Fry et al., 2009). Increased urban landuse should result in increased runoff

(Franczyk and Chang 2009). Therefore, lower runoff may also be caused by increased temperature as indicated by the trends observed in Figure 3.

Table 1. Results of trend analysis of monthly average maximum/minimum temperature at station 025924 and 028815

Month	025924		028815	
	Maximum Temp.	**Minimum Temp.**	**Maximum Temp.**	**Minimum Temp.**
January	**Y = 0.0001x + 14.437**	**Y = 8E-05x - 5.0152**	**y = -4E-05x + 20.359**	**y = 0.0002x - 1.9231**
February	**Y = 8E-05x + 16.77**	**Y = 0.0001x - 4.7075**	**y = -8E-05x + 23.4**	**y = 0.0002x - 0.8515**
March	**Y = 0.0001x + 17.89**	**Y = 0.0001x - 2.1308**	**y = -2E-05x + 24.549**	**y = 0.0003x + 0.3806**
April	**Y = 9E-05x + 23.04**	**Y = 8E-05x + 1.134**	**y = -4E-05x + 29.515**	**y = 0.0003x + 3.8582**
May	**Y = 0.0002x + 25.682**	**Y= 0.0001x + 3.1569**	**y = 2E-05x + 32.467**	**y = 0.0004x + 5.0291**
June	**Y = 9E-05x + 32.469**	**Y = 0.0001x + 9.2723**	**y = 5E-06x + 37.873**	**y = 0.0003x + 11.666**
July	**Y = 7E-05x + 32.536**	**Y = 8E-05x + 15.267**	**y = -6E-05x + 40.1**	**y = 0.0002x + 19.656**
August	**Y = 3E-05x + 32.207**	**Y= 0.0001x + 13.297**	**y = -8E-05x + 39.655**	**y = 0.0002x + 18.24**
September	**Y = 8E-05x + 29.829**	**Y = 1E-04x + 10.186**	**y = -2E-05x + 35.851**	**y = 0.0002x + 14.603**
October	**Y= 4E-05x + 26.673**	**Y = 9E-05x + 3.8587**	**y = -8E-05x + 32.306**	**y = 0.0003x + 6.6498**
November	**Y = 9E-05x + 19.48**	**Y=2E-05x + 0.1623**	**y = -5E-05x + 25.158**	**y = 0.0002x + 2.9574**
December	**Y = 2E-05x + 17.327**	**Y = -1E-05x - 2.0941**	**y = -0.0001x + 22.65**	**y = 0.0001x + 1.28**

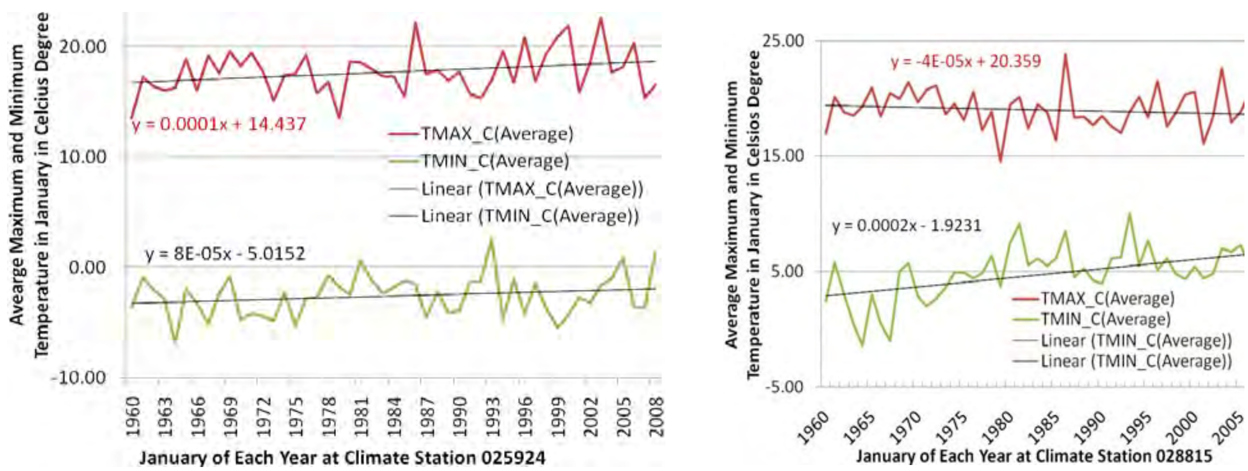

Figure 3. Monthly average Maximum/Minimum temperature of January at stations 025924 and 028815

<u>Peak Discharge at USGS Gauge Station 09485000 and Indication to Soil Erosion and Sediment</u>

Since sediment data are lacking from the watershed, peak discharge from gauging station 09485000 for the period of 1953-2010 was analyzed to provide an indication of potential soil erosion and sediment transport. As shown in Figure 5, peak discharge neither corresponds with rainfall nor corresponds with runoff. For example, the high rainfall in 1983, 1984, 1993 and 2000 did not produce the highest peak although the high rainfall in 1993 produced the high runoff (due to missing runoff data for 1983 and 1984, it is not known if the runoff in 1993 is the highest). The highest peak flow occurred in 2006 when rainfall was about average in that year. This may indicate that the event producing the peak is very high intensity. Higher intensity rainfall has higher rainfall erosivity which potentially produces higher erosion (Renard et al., 1997). Increase in soil erosion can lead to an increase in sediment loading to surface waters which may adversely impact water quality. High peak discharge also indicates high sediment transport (Rankl, 2004). In addition, another possible factor causing high peak discharge is the urban landuse changes. The increased urban area may result in higher peak discharge (Konrad, 2003). In addition to higher erosion potential and sediment transport caused by higher peak discharge, the higher peak discharge also indicates higher flooding risk. Therefore, the watershed is potentially more vulnerable to flooding risk and degraded water quality due to erosion and sediment transport.

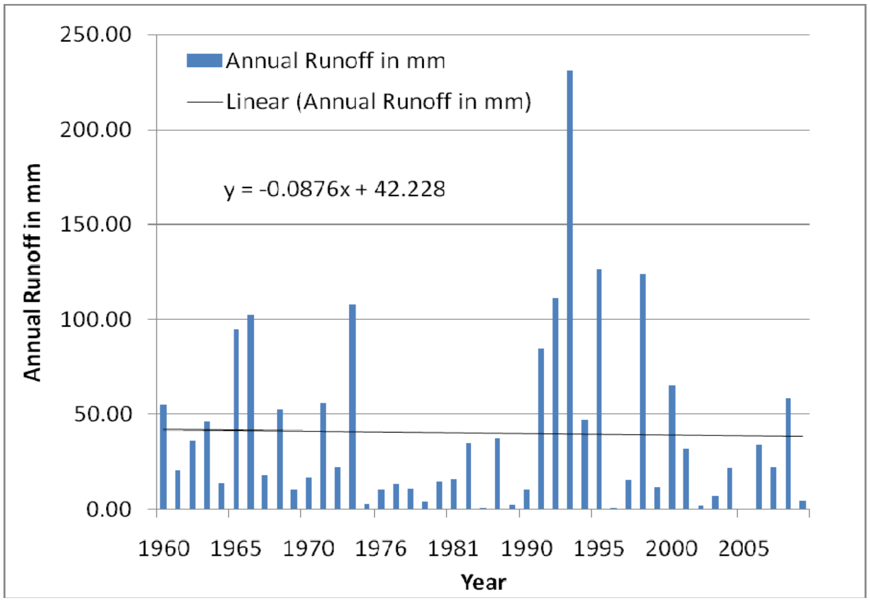

Figure 4. Annual stream flow from USGS gauging stations

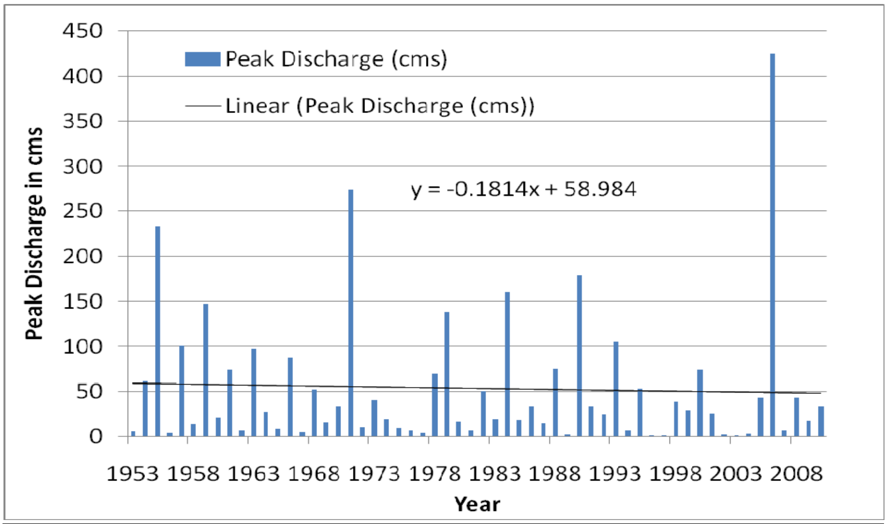

Figure 5. Peak discharge at USGS gauging station 09485000

CONCLUSION

Analyzing climate data and USGS stream gauge data from 1960 to 2008 found that the annual precipitation and runoff have a decreasing trend. The monthly minimum temperature is increasing and the monthly maximum temperature can be increasing or decreasing depending on elevation. Although total annual runoff is decreasing, high peak discharge from individual events was observed which indicates the occurrence of higher intensity rainfall. According to the land use dataset from the US

Geological Survey, the most significant land use change from 1992 to 2001 and from 2001 to 2006 in the upper Santa Cruz watershed was urbanization. Urbanization potentially also causes increased peak discharge. Increased peak discharge potentially results in more soil erosion which leads to increases in sediment loading. Therefore, the watershed is likely more vulnerable to flooding risk and degraded water quality.

Acknowledgements

Although this work was reviewed by USEPA and approved for publication, it may not necessarily reflect official Agency policy. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

References

1. Critchley, W., K. Siegert, C. Chapman, and M. Finkel. 1991. Water harvesting: A manual for the design and construction of water harvesting schemes for plant production. FAO Report No: FAO-AGL--MISC/17/91. Rome: Italy.
2. Daly, C., G. H. Taylor, and W. P. Gibson. 1997. The PRISM approach to mapping precipitation and temperature. Preprints, 10th conf. on applied Climatology, Reno, NV, Amer. Meteor. Soc., 10-12.
3. Di Luzio, M., G.L. Johnson, C. Daly, J.K. Eischeid, and J.G. Arnold. 2008. Constructing retrospective gridded daily precipitation and temperature datasets for the conterminous United States. *Journal of Applied Meteorology and Climatology*. 47(2): 475-497.
4. Franczyk, J., and k.H. Chang. 2009. The effects of climate change and urbanization on the runoff of the rock creek basin in the Portland metropolitan area, Oregon, USA. Hydrological Processes. 23, 805-815
5. Fry, J. A., M. J. Coan, C. G. Homer, D. K. Meyer, and J. D. Wickham. 2009. Completion of the National Land Cover Database (NLCD) 1992–2001 Land Cover Change Retrofit product. U.S. Geological Survey.
6. Ghaffari G., S. Keesstra, J. Ghodousi, H. Ahmadi. 2009. SWAT-simulated hydrological impact of land-use change in the Zanjanrood Basin, Northwest Iran. *Hydrological Processes* 24(7): 892-903.
7. Homer, C., C. Huang, L. Yang, B. Wylie, and M. Coan. 2004. Development of a 2001 National Landcover Database for the United States. *Photogrammetric Engineering and Remote Sensing* 70(7): 829-840.
8. Konrad, C.P. 2003. Effects of Urban Development on Floods. USGS Fact Sheet FS-076-03. Available at: http://pubs.usgs.gov/fs/fs07603/pdf/fs07603.pdf. Accessed on May 4, 2011.
9. Rankl, J. G. 2004. Relations between Total-Sediment Load and Peak Discharge for Rainstorm Runoff on Five Ephemeral Streams in Wyoming. U.S. Department of the Interior U.S. Geological Survey Water-Resources Investigations Report 02-4150. Reston, Virginia.
10. Renard, K. G., G. R. Foster, G. A. Weesies, D. K. McCool, and D. C. Yoder, coordinators. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA Agriculture Handbook No. 703.
11. US Geological Survey (USGS) - Mexico Border Environmental Health Initiative (BEHI) http://borderhealth.cr.usgs.gov/projectindex.html. Accessed in March, 2011.