Assessing Hydrologic Impacts of Future Land Change Scenarios in the San Pedro River (U.S./Mexico)

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Background

Long-term land-use and land cover change and their associated impacts pose critical challenges to sustaining vital hydrological ecosystem services for future generations. Scenario analysis is an important tool to help understand and predict potential impacts caused by decisions regarding conservation and development. In this study, a methodology was developed to characterize the hydrologic impacts of future urban growth through time. This project 1) describes a methodology for adapting the Integrated Climate and Land-Use Scenarios (ICLUS, Bierwagen et al., 2010; EPA, 2009; EPA, 2010) data for use in the Automated Geospatial Watershed Assessment Tool (AGWA; Miller et al. 2007) as an approach to evaluate basin-wide impacts of development on water quantity and quality, 2) presents initial results from the application of the methodology to evaluate water scenario analyses related to baseline condition and forecasted changes, and 3) discusses implications of the analysis for the San Pedro River (Figure 1), an arid international watershed on the U.S./Mexico border.

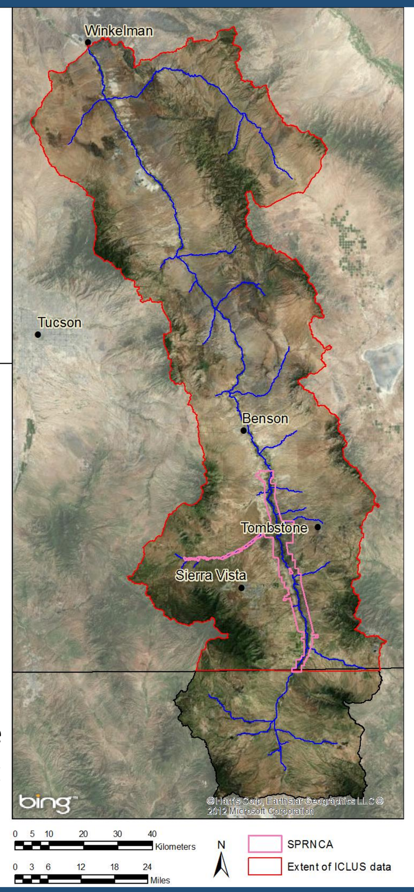


Figure 1. The study area contains the entire San Pedro Watershed (~11500 km^2) from Sonora, Mexico to the historic USGS stream gage #09473500 in Winkelman, AZ. The San Pedro River flows 230 km from Sonora to the Gila River in Arizona. It has significant ecological value, supporting one of the highest numbers of mammal species in the world and providing critical habitat and a migration corridor to several hundred bird species.

Global Scenario		Demographic Model			Spatial Allocation Model	
		Fertility	Domestic Migration	Net International Migration	Household Size	Urban Form
A1	medium population growth; fast economic development; high global integration	low	high	high	smaller (-15%)	no change
B1	medium population growth; low domestic migration resulting in compact urban development	low	low	high	smaller (-15%)	slight compaction
A2	high population growth; greatest land conversion; high domestic migration resulting in new population centers	high	high	low	larger (+15%)	no change
B2	moderate economic development; medium population growth; medium international migration	medium	low	low	no change	slight compaction
Baseline (2000)	US Census medium Scenario	medium	medium	medium	no change	no change

Table 1. Summary of the qualitative types of changes of the different ICLUS scenarios. ICLUS developed future housing density maps by adapting the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) social, economic, and demographic storylines to the conterminous United States.

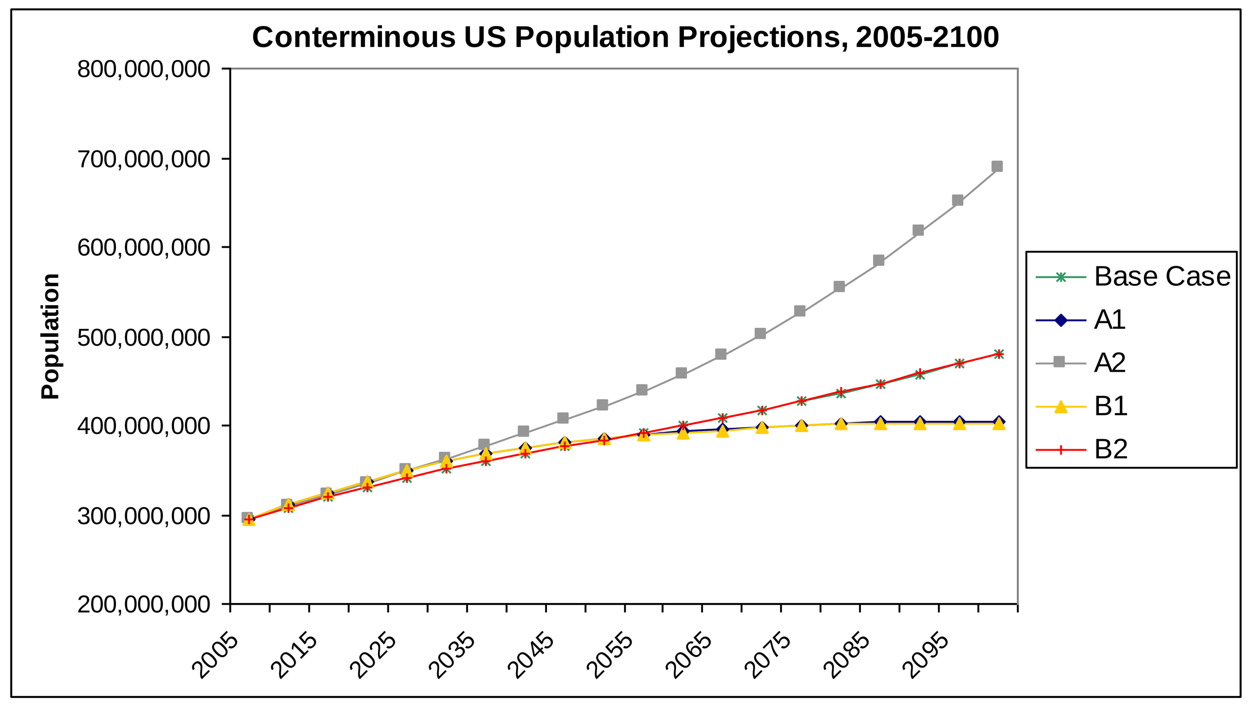


Figure 2. Total population under five ICLUS scenarios. Scenario B2 and the base case have the same population trajectories, as do scenarios A1 and B1, however the housing density in different areas varies under the different scenarios due to different domestic migration rates.

Methodology

The methodology developed in this project to ascertain local vulnerabilities and cumulative impacts associated with basin-wide development is a multi-step process. First, the project/watershed extent must be defined to ensure that data is obtained for the entire study area. The various land cover data must then be converted to a format compatible with AGWA in a manner that is consistent with existing land cover in the study area. Next, soils and precipitation data for the study area must be located and extracted. Finally, AGWA is used to parameterize and run the Soil and Water Assessment Tool (SWAT; Neitsch et al. 2002; Srinivasan and Arnold 1994) for the baseline condition and future land cover/use scenarios. Future land cover/use scenarios are represented by ICLUS housing density maps generated in decadal intervals from 2010 to 2100, reclassified to National Land Cover Database 2006 land cover classes for use in AGWA to parameterize the SWAT model (Figures 2-4, Tables 1-4).

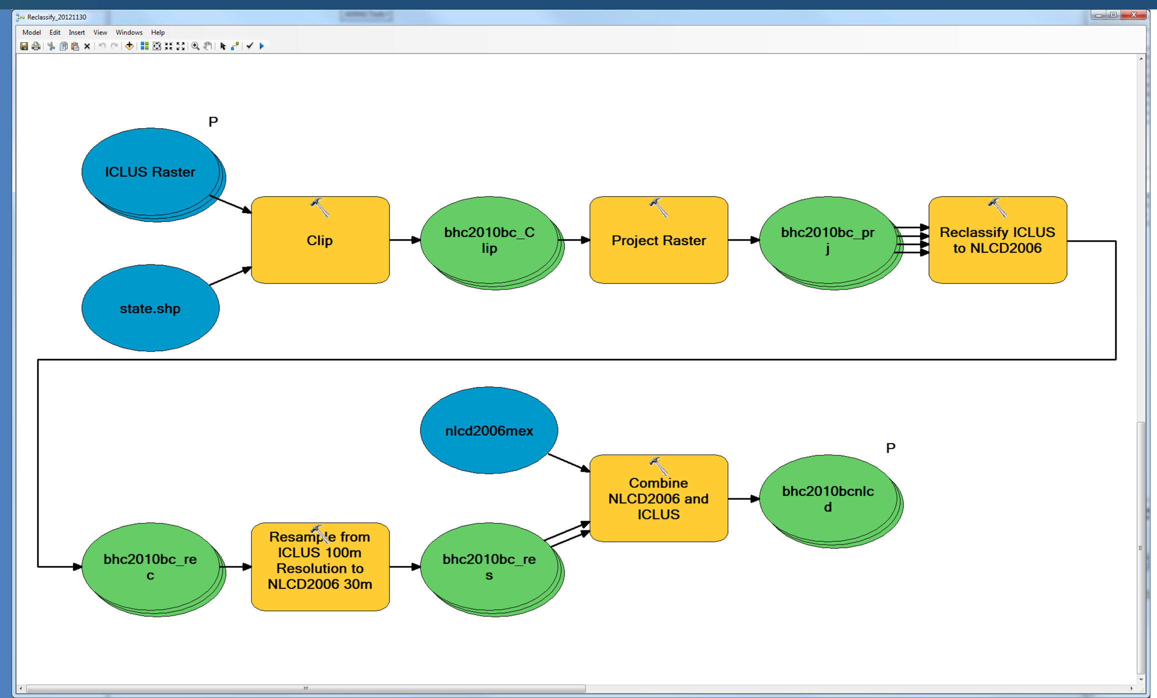
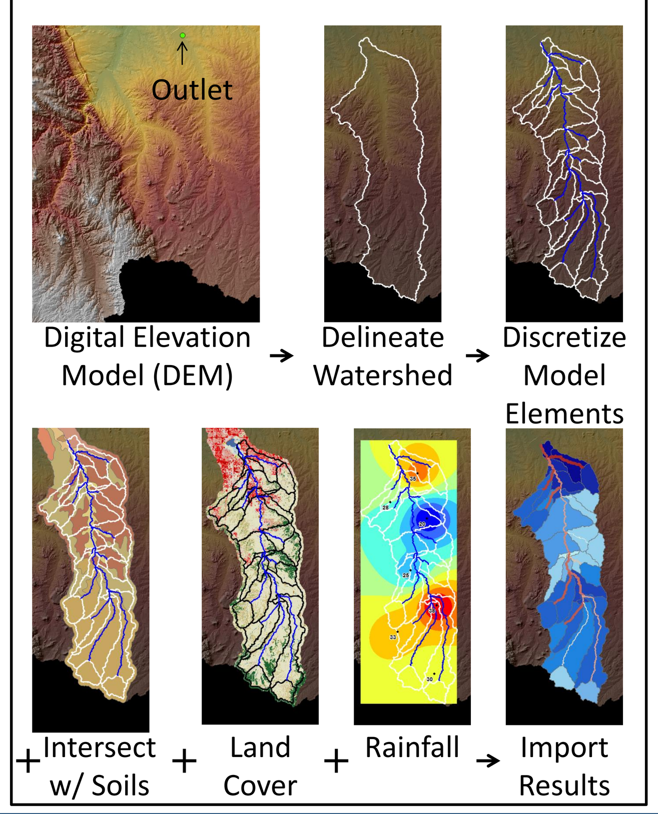


Figure 3. Geoprocessing model to clip, project, and reclassify the ICLUS data into classified land cover for use in AGWA.

Figure 4. AGWA Conceptualization



1992 NALC (Mexico)		2006 NLCD	
Code	Land Cover Type	Code	Land Cover Type
1	Forest	42	Evergreen Forest
2	Oak Woodlands	41	Deciduous Forest
3	Mesquite Woodlands	52	Scrub/Shrub
4	Grasslands	52	Scrub/Shrub
5	Desert Scrub	52	Scrub/Shrub
6	Riparian	90	Woody Wetlands
7	Agricultural	82	Cultivated Crops
8	Urban	22	Developed, Medium Intensity
9	Water	11	Open Water
10	Barren	31	Barren Land
11	Clouds	31	Barren Land

Table 2. Reclassification table for 1992 North American Landscape Characterization Project (NALC; EPA, 1993) to National Land Cover Database 2006 (NLCD; Fry et al., 2011). NALC data was used for the Mexico portion of the watershed due to the more current NLCD availability being limited to the United States.

Class	Acres per housing unit	Housing units per acre	Hectares per housing unit	Housing units per hectare	Density category
99	NA	NA	NA	NA	Commercial/Industrial
4	<0.25	>4	<.1	>10	Urban
3	0.25-2	0.5-4	0.1-0.81	1.23-10	Suburban
2	2-40	0.025-2	0.81-16.19	0.06-1.23	Exurban
1	>40	<0.025	>16.19	<0.06	Rural

Table 3. Description of ICLUS housing density categories.

ICLUS Data		2006 NLCD	
Code	Land Cover Type	Code	Land Cover Type
1	Rural	-	Default to NLCD cover type
2	Exurban	22	Developed, Low Intensity
3	Suburban	23	Developed, Medium Intensity
4	Urban	24	Developed, High Intensity
99	Commercial/Industrial	24	Developed, High Intensity

Table 4. Reclassification table for ICLUS housing density classes to 2006 NLCD land cover types.

Results

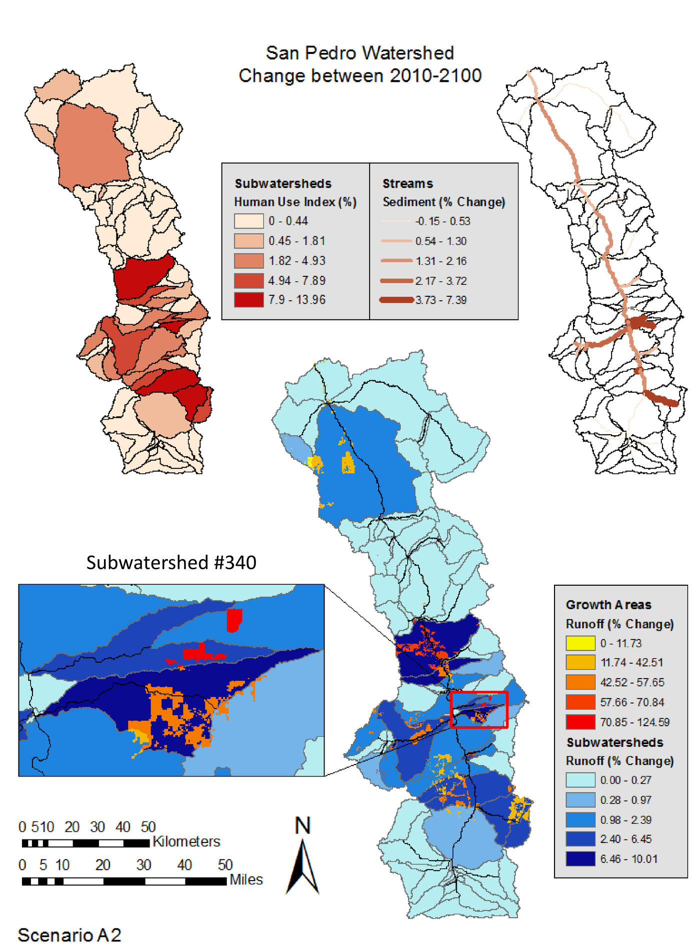
All scenarios experienced an increase in the Human Use Index metric averaged over the entire watershed. The Human Use Index (HUI; adapted from Ebert and Wade, 2004) is the percent area in use by humans. It includes NLCD land cover classes "Developed, Open Space"; "Developed, Low Intensity"; "Developed, Medium Intensity"; "Developed, High Intensity"; "Pasture/Hay"; and "Cultivated Crops" (Figure 5). The ICLUS A2 scenario resulted in the largest increase of the HUI, 2.21% in year 2100 for the entire watershed (see Figure 7). Similarly to the increases in HUI over the entire watershed, both simulated runoff and sediment yield increased at the watershed outlet over time for all scenarios; likewise, scenario A2 experienced the largest percent change in surface runoff and sediment yield, 1.04% and 1.19%, respectively (see Figure 8 and 9). Percent change was calculated using the following equation:

$$\frac{([decade_i] - [base_i])}{[base_i]} \times 100$$

where [*decade*$_i$] represents simulation results for a decade from 2020 through 2100 for a given scenario (*i*) and [*base*$_i$] represents the baseline 2010 decade for the same scenario.

At the subwatershed scale, increases in HUI, runoff, and sediment yield are more pronounced than at the watershed scale because they are not averaged out by large swaths of undevelopable land (Figures 5 and 7-12)

Figure 5. Change in Human Use Index (HUI), sediment yield, and surface runoff (both average and explicit) in percent from 2010 to 2100 for scenario A2. Explicit percent change, or change in the growth areas, is calculated by dividing the effective percent change, i.e. the average percent change over the entire subwatershed, by the ratio of changed land cover area to entire subwatershed area.



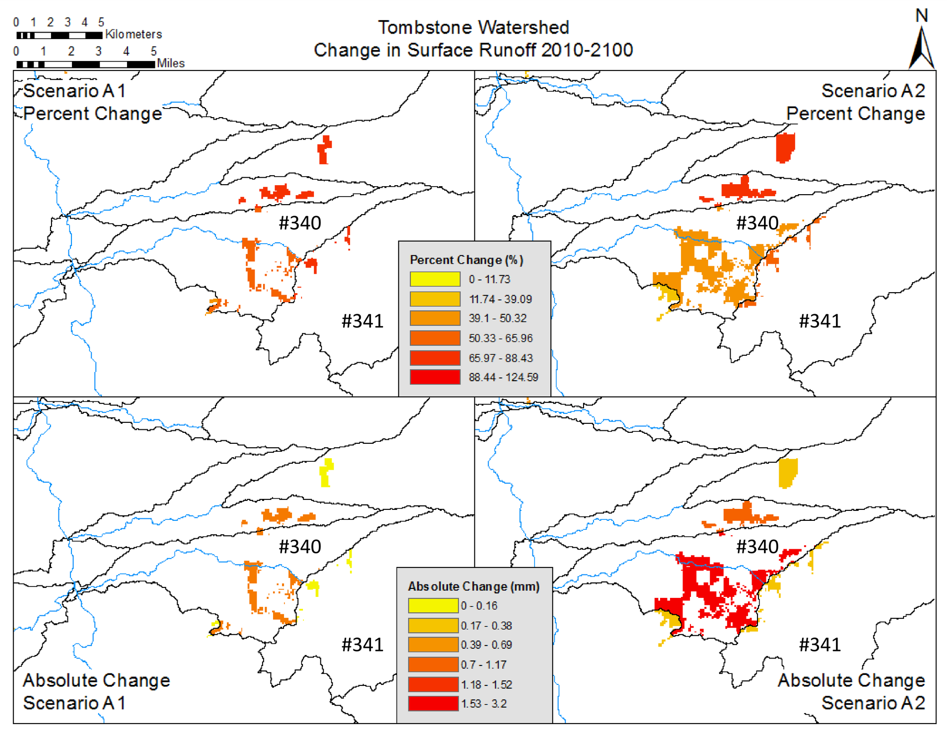


Figure 6. Subwatersheds #340 and #341 for scenarios A1 and A2 from 2010 to 2100 show how a larger absolute change in one scenario can undergo a smaller explicit percent change (average subwatershed percent change divided by the ratio of changed land cover area to entire subwatershed area). Explicit percent change emphasizes that local change may be much greater than average watershed or even average subwatershed percent change can describe.

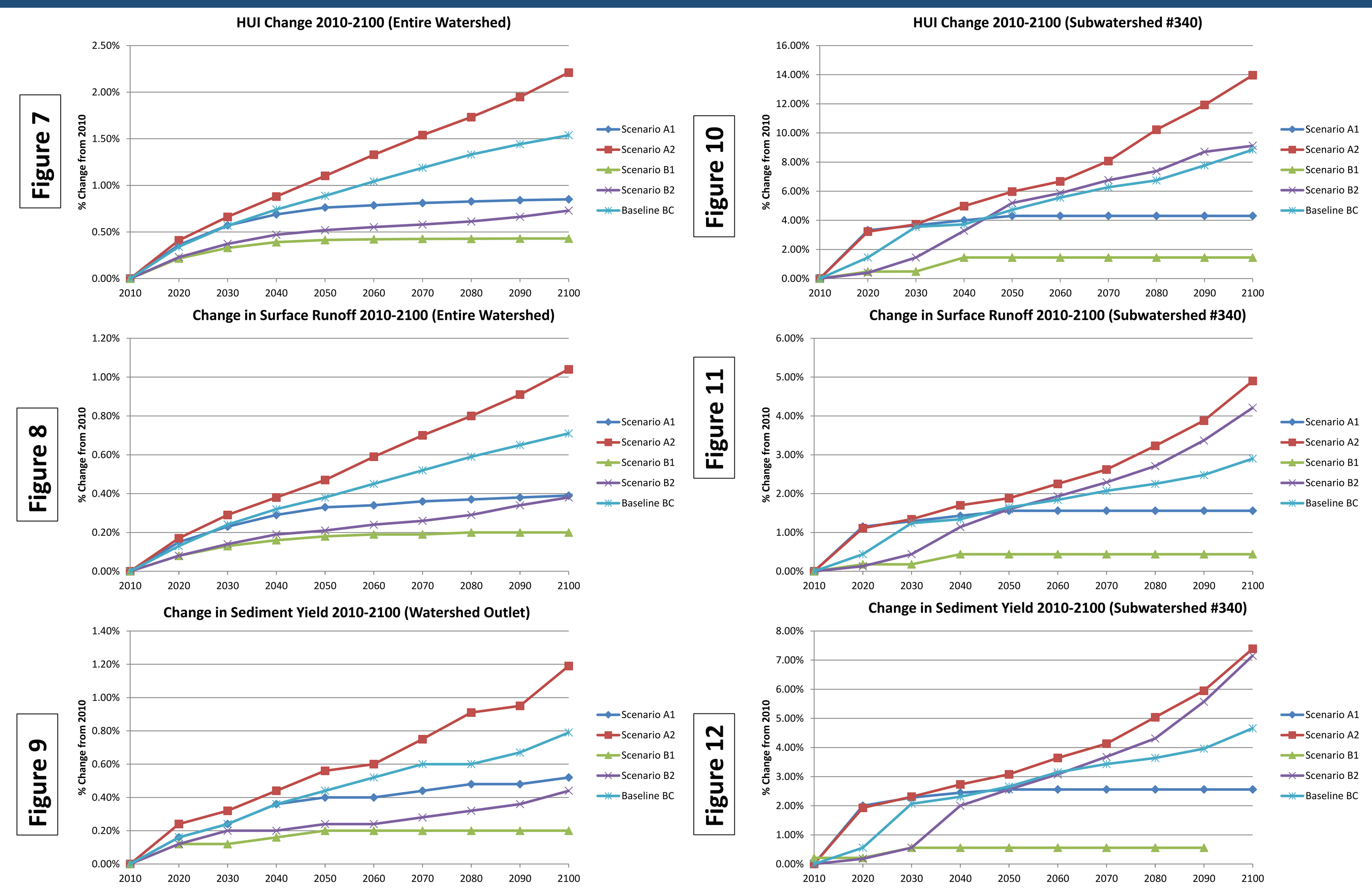


Figure 7 through 12. Change in Human Use Index (HUI), sediment yield, and surface runoff for all scenarios and decades at the watershed outlet (left) and at the subwatershed with the highest change (right). The pattern is similar at the watershed outlet and the selected subwatershed, but the magnitude of change is greater at the subwatershed scale because at the subwatershed scale, local changes are not attenuated by large undevelopable areas.

Discussion

The results emphasize the importance of including scrutiny of individual subwatersheds and the explicit areas that change in a basin-scale assessment as the impacts at the subwatershed scale and below can be much greater than at the basin scale. Because the San Pedro Watershed is so large and has a significant undevelopable portion, the changes that are occurring in developable subwatersheds need to be examined at a larger scale. At the subwatershed scale, unacceptable hydrologic impacts may be observed that would otherwise be captured at the basin scale if development was occurring basin-wide. Instead, basin-wide impacts are effectively averaged out by undevelopable lands. Thus any interests in cumulative affect should be addressed at the subwatershed versus basin scale for this western watershed or others like it which are characterized by large tracts of land in the public domain which are undevelopable, and therefore not subject to direct urbanization impacts.

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The Automated Geospatial Watershed Assessment Tool
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