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

RESEARCH AND DEVELOPMENT

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

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This report has been subjected to both the EPA/ORD and USDA/ARS peer and administrative review processes and has been approved for publication. The Automated Geospatial Watershed Assessment (AGWA) tool was jointly developed by EPA/ORD, USDA/ARS, and the University of Arizona. The Integrated Climate and Land Use Scenarios (ICLUS) database was developed by EPA/ORD. AGWA and ICLUS are endorsed and recommended by each of the respective agencies, especially in regard to their integrated use.

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Acronyms and Abbreviations

ACOE	Army Corps of Engineers
AGWA	Automated Geospatial Watershed Assessment
ARS	Agricultural Research Service
BC	Base Case
BLM	U.S. Bureau of Land Management
CWA	Clean Water Act
DEM	Digital Elevation Model
DOD	Department of Defense
DST	Decision Support Tools
EPA	U.S. Environmental Protection Agency
FWS	U.S. Fish and Wildlife Service
GIS	Geographic Information System
HD	Housing Density
HUI	Human Use Index
ICLUS	Integrated Climate and Land-Use Scenarios
IPCC	Intergovernmental Panel on Climate Change
NALC	North American Landscape Characterization
NCDC	National Climatic Data Center
NCGC	National Cartography and Geospatial Center
NED	National Elevation Dataset
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service

RARE	Regional Applied Research Effort
SRES	Special Report on Emissions Scenarios
SPRNCA	San Pedro Riparian National Conservation Area
STATSGO	State Soil Geographic database
SWAT	Soil and Water Assessment Tool
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGS	U.S. Geological Survey

Abstract

Long-term land-use and land cover change and their associated impacts pose critical challenges to sustaining vital hydrological ecosystem services for future generations. In this study, a methodology was developed to characterize hydrologic impacts from future urban growth through time. Future growth is represented by housing density maps generated in decadal intervals from 2010 to 2100, produced by the U.S. Environmental Protection Agency (EPA) Integrated Climate and Land-Use Scenarios (ICLUS) project. 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. To characterize hydrologic impacts from future growth, the housing density maps were reclassified to National Land Cover Database (NLCD) 2006 land cover classes and used to parameterize the Soil and Water Assessment Tool (SWAT) using the Automated Geospatial Watershed Assessment (AGWA) tool. The objectives of this project were to 1) develop and describe a methodology for adapting the ICLUS data for use in AGWA as an approach to evaluate basin-wide impacts of development on water-quantity and -quality, 2) present initial results from the application of the methodology to evaluate water scenario analyses related to a baseline condition and forecasted changes, and 3) discuss implications of the analysis for the San Pedro River Basin, an arid international watershed on the U.S./Mexico border.

Introduction

Changes in land-use and land cover are critical in the determination of water availability, quality, and demand. The consequences of human modification to the Earth's surface for extraction of natural resources, agricultural production, and urbanization may rival those that are anticipated via climate change (Vitousek 1994, Vörösmarty et al. 2000, Chapin et al. 2002, DeFries and Eshleman 2004, Brauman et al. 2007, Whitehead et al. 2009, Triantakonstantis and Mountrakis 2012). Responding to change requires improvements in our ability to understand vulnerabilities and to develop processes and metrics to better understand the consequences of choice. It also requires an ability to communicate highly technical information to risk managers and decision makers.

Scenario analysis provides the capability to explore pathways of change that diverge from baseline conditions and lead to plausible future states or events. Scenario analysis has been used extensively in studies related to environmental decision support (USDI 2012). Although a number of scenario frameworks are available to assist in evaluating policy or management options, most are designed to analyze alternative futures related to decision options, potential impacts and benefits, long-term risks, and management opportunities (Steinitz et al. 2003, Kepner et al. 2012, March et al. 2012). They frequently are combined with process modelling and are intended to bridge the gap between science and decision making and are effective across a range of spatial and temporal scales (Liu et al. 2008a and 2008b, Mahmoud et al. 2009).

This report describes a methodology to integrate a widely used watershed modeling tool and a consistent national database with alternative future scenarios which can then be scaled to regional applications. This report further describes the cumulative impacts of housing densities parsed out at decadal intervals to the year 2100 on a hydrological ecosystem consisting primarily of ephemeral and intermittent waters.

Ephemeral waters are extremely important in the arid west and Arizona as a key source of groundwater recharge (Goodrich et al. 2004) and providing important near channel alluvial aquifer recharge to support aquatic ecosystems in downstream perennial and intermittent streams (Baille et al. 2007). They also provide critical ecosystem services supporting numerous species (Levick et al. 2008). In addition, the beneficial uses of main-stem rivers cannot be meaningfully protected if their supporting watersheds are degraded through significant hydrological and ecological modifications (Brooks et al. 2007a and 2007b). The U.S. Environmental Protection Agency (EPA) supports a watershed approach to resource restoration and protection, exemplified by the San Pedro River watershed, a globally-important watershed described in the case study presented here.

At present, issuance of U.S. Army Corps of Engineers (ACOE) Clean Water Act (CWA) Section 404 permits are carried out in a project-by-project fashion with little consideration of how multiple projects might collectively impact hydrology and biodiversity. However, the cumulative impact of multiple projects on watershed function is a concern. From Part 11(g) of Part 230 – Section 404(B) (1) Guidelines for Specification of Disposal Sites for Dredged or Fill Material (Guidelines), "…cumulative impacts are the changes in an aquatic ecosystem that are attributable to the collective effect of a number of individual discharges of dredged or fill material." Although the impact of a particular discharge may constitute a minor change in itself, the cumulative effect of numerous such changes can result in degradation and impairment of the water resources, interfering with the productivity and overall integrity of biological, chemical, and physical processes of aquatic ecosystems. Section 230.11 of the Guidelines describes special conditions for evaluation of proposed permits to be issued, which includes the evaluation of potential individual and cumulative impacts of the category of activities to be regulated under general permit. The Guidelines constitute the substantive environmental criteria used in evaluating activities regulated under Section 404. Section 404 requires a permit before dredged or fill material may be discharged into the waters of the United States. The Guidelines state the terms *aquatic environment* and *aquatic ecosystem* mean waters of the United States, including wetlands, that serve as habitat for interrelated and interacting communities and populations of plants and animals (part 230.3[c]), and that "waters of the United States" includes tributaries (part 230.3[s]).

In an effort to build an improved capability for environmental decision makers and managers to plan and respond to potential change, the EPA, U.S. Department of Agriculture (USDA) Agricultural Research Service, and the University of Arizona have recently initiated two projects under the Regional Applied Research Effort (RARE) Program. The two case studies selected for this project are the San Pedro River (U.S./Mexico) in EPA Region 9 and the South Platte River Basin (CO, WY, and NE) in EPA Region 8.

For the purpose of this report, the results are restricted to the San Pedro River. The intent is to quantitatively evaluate hydrologic impacts of future developments at the basin scale, which intrinsically addresses the cumulative impact of multiple housing development projects. The study area encompasses the entire San Pedro Watershed (~11500 km^2 or ~4440 mi^2) from

Sonora, Mexico to the stream gage (USGS 09473500) in Winkelman, AZ (Figure 1). The San Pedro River flows 230 km from its headwaters in Sonora, Mexico to its confluence with the Gila River in central Arizona. It is nationally known as one of the last free-flowing rivers in the Southwest. It has significant ecological value, supporting one of the highest numbers of mammal species in the world and providing crucial habitat and a migration corridor to several hundred bird species. Vegetation ranges from primarily semi-desert grassland and Chihuahuan desert scrub in the Upper San Pedro to primarily Sonoran desert scrub and semi-desert grassland in the Lower San Pedro. The Upper San Pedro is home to the San Pedro Riparian National Conservation Area (SPRNCA). It was designated as the first National Conservation Area for riparian protection by Congress in 1988. The SPRNCA protects approximately 64 kilometers (~40 miles) of river and is administered by the U.S. Department of the Interior, Bureau of Land Management (Kepner et al. 2004, Bagstad et al. 2012).

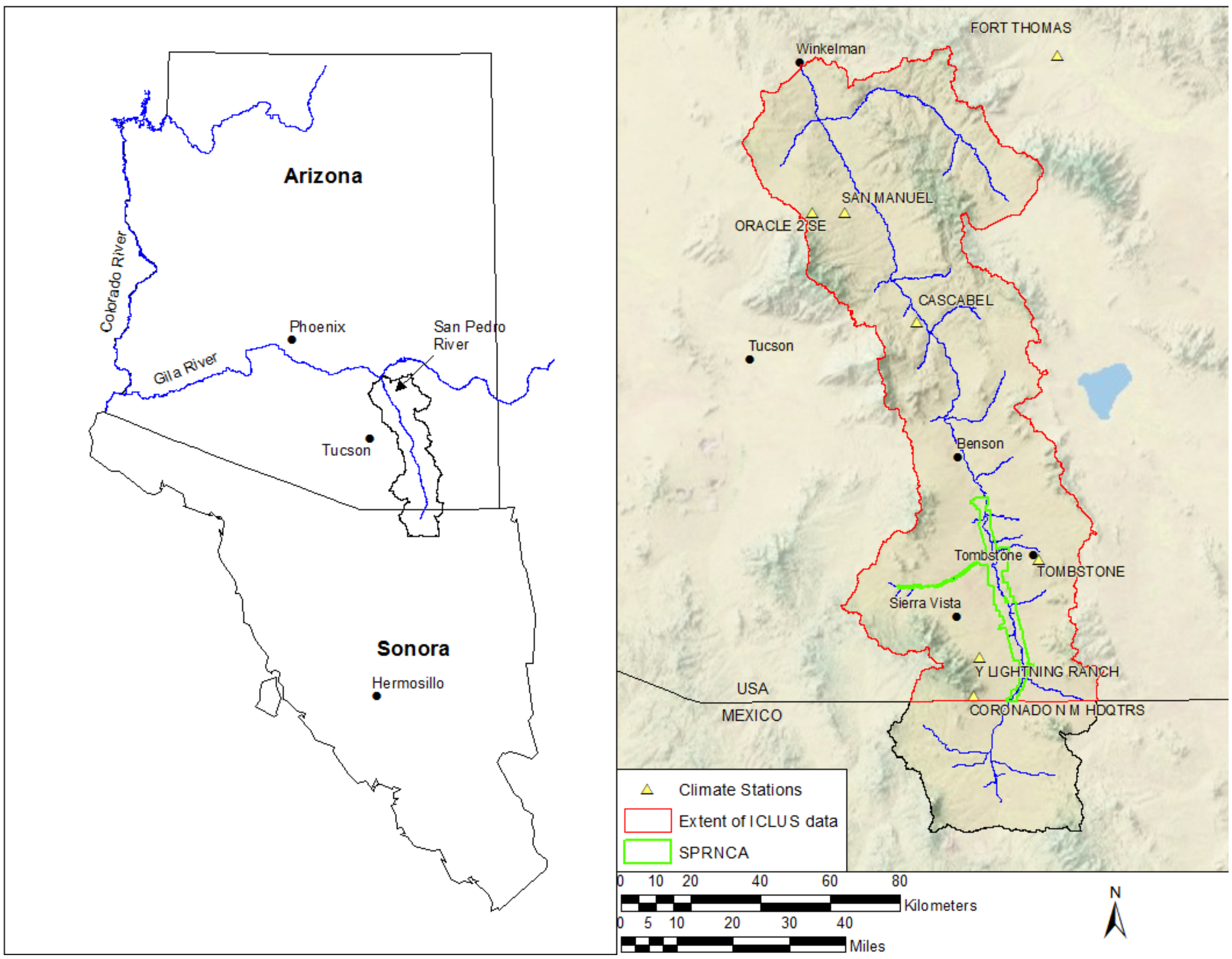


Figure 1: Location Map of the Study Area Contrasting the Extent of the ICLUS Data Used in the Future Scenarios to the San Pedro Watershed.

An underlying premise of this project is that watershed assessments can be significantly improved if environmental resource managers have Decision Support Tools (DSTs) that are easy-to-use, access readily available data, and are designed to address hydrologic and water quality processes that are influenced by development at both the project-and basin-wide scale.

The Automated Geospatial Watershed Assessment (AGWA; Miller et al. 2007; http://www.epa.gov/esd/land-sci/agwa/index.htm *and* http://www.tucson.ars.ag.gov/agwa) tool, i.e. the DST used in this project, will assist the EPA and other agencies with permitting and enforcement responsibilities under CWA Sections 401, 404 (FWS, NOAA, and ACOE), 402, 311 (US Coast Guard and states), and CWA 319 grant recipients (states, tribes, and local organizations). It is designed to identify areas that are most sensitive to environmental degradation as well as areas of potential mitigation or enhancement opportunities, and thus inform restoration, permitting, and enforcement strategies. AGWA is recognized as one of the world's primary watershed modeling systems (Daniel et al. 2011) providing the utility to generate hydrologic responses at the subwatershed scale and spatially visualize results for qualitative comparisons (*also see* http://cfpub.epa.gov/crem/knowledge_base/crem_report.cfm?deid=75821).

Methods

The methodology developed 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 are obtained for the entire study area. The various land cover data must then be converted to a format compatible with AGWA. 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.

Project/Watershed Extent

Defining an accurate project and watershed extent is a critical first step that will minimize difficulties later because this extent is used to locate other required data, including land cover, soils, precipitation, and climate data. To define the project extent, the project watershed is delineated in AGWA and given a buffer distance of 500 meters. The watershed is delineated using a 10-meter digital elevation model (DEM) that has been hydrologically corrected to ensure proper surface water drainage. In the United States (and for basins extending into Mexico), the U.S. Geological Survey (USGS) *The National Map* Viewer and Download Platform (http://nationalmap.gov/viewer.html) maintains the National Elevation Dataset (NED; http://ned.usgs.gov/), which is a recommended source for DEM data. The delineated watershed is buffered 500 meters to establish the project extent and ensure there are no gaps in coverage for the land cover and soils data.

Land Cover

The land cover data used in this report comes from an array of sources. Because the project extent includes Mexico, a land cover dataset with coverage in Mexico must be used. The National Land Cover Database 2006 (NLCD; Fry et al. 2011), available nationally in the United States, is used as the base land cover for the United States. It does not include the Mexico portion of the watershed however, so the North American Landscape Characterization Project (NALC; EPA, 1993), which has national coverage of both Mexico and the United States up to 1992, was used as source imagery for the derived land cover for Mexico (Kepner et al. 2000, Kepner et al. 2003, Figure 1). The Integrated Climate and Land-Use Scenarios (ICLUS; Bierwagen et al. 2010; EPA, 2009; EPA, 2010) project data were identified as an ideal dataset for projecting basin-wide development into the future because its national-scale housing-density (HD) scenarios are consistent with the Intergovernmental Panel on Climate Change (IPCC 2001) Special Report on Emissions Scenarios (SRES; Nakicenovic and Swart 2000) greenhouse gas emissions storylines (Table 1, Figure 2). Though the NALC data has coverage for the entire watershed the NLCD is used for the United States because it is the most current dataset available and because others have utilized NLCD (from 2001 instead of 2006) with ICLUS data to project future growth (Johnson et al. 2012).

Table 1: Summary of the Types of Changes of the Different ICLUS Scenarios.

National 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
Base Case (2000)	U.S. Census medium scenario	medium	medium	medium	no change	no change

Because the 2006 NLCD and 1992 NALC datasets have different classifications, the NALC land cover is reclassified to match the NLCD land cover (Table 2). The reclassified NALC dataset of Mexico is then combined with the 2006 NLCD dataset of the U.S. resulting in a derived NLCD dataset that covers the entire project extent. Note that the “Grasslands” class in the NALC dataset was reclassified to “Scrub/Shrub” to be consistent with the observed classification methodology of the NLCD. For applications entirely within the United States, the

NLCD land cover will not need to be combined with other datasets, simplifying the process and application of this methodology.

The ICLUS HD data is combined with the NLCD/NALC data to project future development by decade to 2100. The ICLUS data has five categories of housing density representing rural, exurban, suburban, urban, and commercial/industrial (Table 3).

Table 2: Reclassification Table for 1992 NALC in Mexico to 2006 NLCD Land Cover Types.

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

Table 3: Explanation of ICLUS Housing Density Categories.

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	<0.1	>10	Urban
3	0.25-2	0.5-4	0.1-0.81	1.23-10	Suburban
2	2-40	0.025-0.5	0.81-16.19	0.06-1.23	Exurban
1	>40	<0.025	>16.19	<0.06	Rural

The ICLUS database produced 5 seamless, national-scale change scenarios for urban and residential development (Table 1). The A2 Scenario is characterized by high fertility and low net international migration; it represents the highest population scenario gain (690 million people by 2100). The Base Case (BC) and Scenario B2 are the middle scenarios, with medium fertility and medium to low international migration. Differences between BC and B2, as well as A1 and B1, reflect how housing is allocated – sprawl vs. compact growth patterns. As a result of this distinction, the county populations in urban and suburban areas generally grow faster than in rural areas in the base case, but the experiences of individual counties vary. A1 and B1, with low fertility and high international migration are the lowest of the population scenarios. The primary difference between these scenarios occurs at the domestic migration level, with an assumption of high domestic migration under A1 and low domestic migration under B1. The effect of different migration assumptions becomes evident in the spatial model when the population is allocated into housing units across the landscape. The Baseline forecast for 2100 is 450M people and B1 could be lower at 380M people. The A2 scenario results in the largest changes in urban and suburban housing density classes and greater conversion of natural land-cover classes into new population centers, or urban sprawl. The largest shift from suburban densities to urban occurs in 2050 – 2100 for the A-family scenarios (Bierwagen et al. 2010, Figure 2). The ICLUS scenarios were developed using a demographic model to estimate future populations through the year 2100 and then allocated to 1-hectare pixels by county for the conterminous U.S. (EPA 2009, EPA 2010). The final data sets provide decadal projections of both housing density and impervious surface cover from the 2000 baseline year projected out to the year 2100.

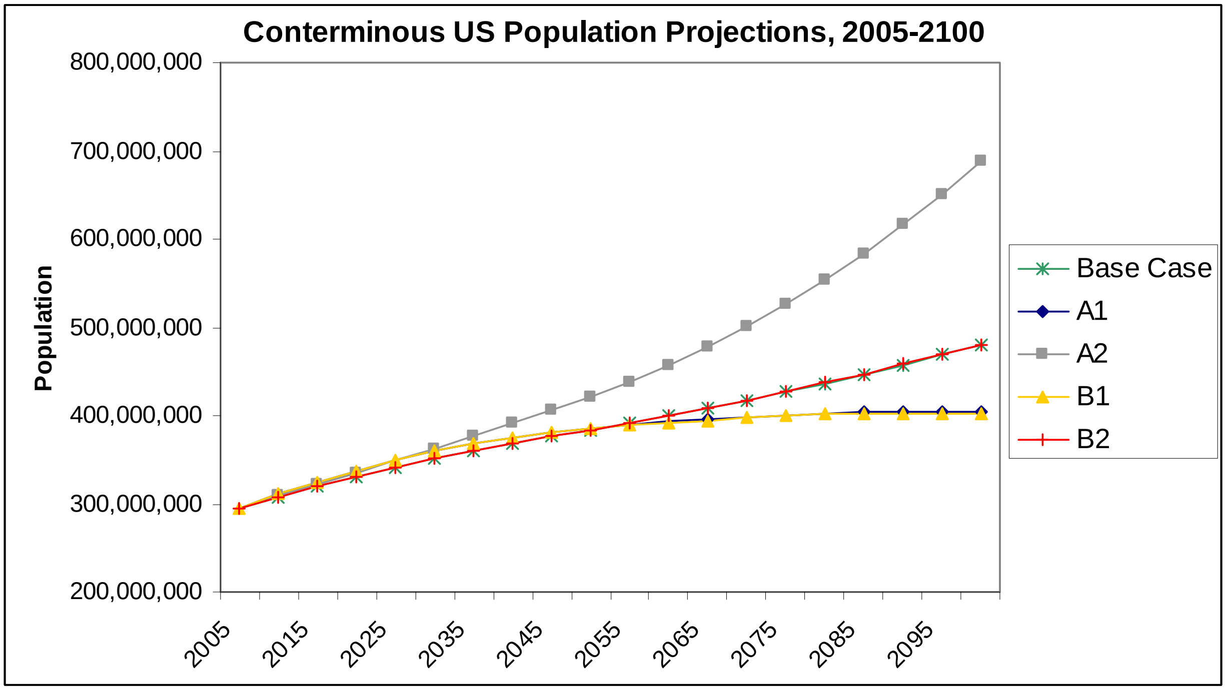


Figure 2: Population Projections for ICLUS Scenarios by Decade.

The NLCD data has different land cover classes, a different projection, and is at a different resolution (30m) than the ICLUS data (100m); therefore the ICLUS data were pre-processed for use in this project. Preprocessing includes clipping the ICLUS data to the boundary of Arizona, projecting the ICLUS data to UTM Zone 12 NAD83, reclassifying the ICLUS data to NLCD classes (Table 4) and resampling the ICLUS data from 100m to 30m. The resulting dataset was then merged with the NLCD dataset so the ICLUS data replaced the NLCD data if there was a change in land cover. The reclassification scheme was determined based on housing density definitions, which were different between the two datasets. As a result the "Rural" land cover type in the ICLUS data was defaulted to the NLCD class present at that location. This methodology was incorporated into a tool in ArcToolbox in ArcGIS for easy conversion of the ICLUS datasets (Appendix A, Figure 15).

Table 4: Reclassification Table for ICLUS Housing Density Classes to 2006 NLCD Land Cover Types.

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

For the purposes of developing the methodology, only scenario A1 (corresponding to storyline A1 in the SRES) of the ICLUS data was used in an interim report (Burns et al. 2012), however all five ICLUS scenarios (A1, A2, B1, B2, and BC) were used in this final report.

Ten land cover datasets per scenario (50 total) are produced from the combination of the NLCD/NALC datasets and the ICLUS datasets, representing the change in landscape attributed to population and development changes by decade from 2010 to 2100. Tables 9 through 13 in Appendix C contain the changes in land cover/use by decade for each of the ICLUS national scenarios. For each scenario, the dataset from 2010 is used as the project baseline to which the successive decadal datasets are compared.

Soils

Soils data for the U.S. were obtained from the Natural Resources Conservation Service (NRCS) - National Cartography and Geospatial Center's (NCGC) State Soil Geographic (STATSGO; USDA-NRCS 1994) database. Soils data for Mexico were obtained from the San Pedro Data Browser (Kepner et al. 2003, Boykin et al. 2012). STATSGO and the Mexico soils have different soil definitions and the Mexico soils are not supported directly in AGWA, so the Mexico soil types were matched and redefined to equivalent STATSGO soil types. Because neither dataset covered the entire project extent, the redefined Mexico soils were merged with the STATSGO dataset to create a seamless coverage of the entire project extent. The mapping scale of the two datasets is somewhat generalized with a mapping scale of 1:250,000, but nonetheless they are suitable for this application given the watershed size and focus on hydrologic response due to land cover change. For applications entirely within the United States, the STATSGO dataset will not need modification or merging with other soil layers, simplifying the process and application of this methodology.

Precipitation

Precipitation data obtained from the National Climatic Data Center (NCDC; http://www.ncdc.noaa.gov/) were used to drive the SWAT model in AGWA. Climate stations in the vicinity of the San Pedro Watershed were reviewed for periods of record and completeness of the dataset. The review produced a total of seven climate stations in Arizona with the recorded precipitation needed for the SWAT model (Table 5, Figure 1). Values of "-99" were used in place of missing data in the period of record to flag SWAT to use its built-in stochastic weather generator to determine how much precipitation to supply for the missing records. The period of record is from 1971-2001.

Table 5: Climate Stations Used from the NCDC.

Cooperative Station ID	Station Name
21330	Cascabel
22139	Coronado National Monument Headquarters
23150	Fort Thomas
26119	Oracle 2 SE
27530	San Manuel
28619	Tombstone
29562	Y Lightning Ranch

AGWA-SWAT Modeling

The AGWA tool was used to model the San Pedro Watershed with the SWAT model. The AGWA tool is a user interface and framework that couples two watershed-scale hydrologic models, the KINematic Runoff and EROSion model (KINEROS2; Semmens et al. 2008) and the Soil and Water Assessment Tool (SWAT; Arnold et al. 1994), within a geographic information system (GIS). The coupling of hydrologic models and GIS within the AGWA tool performs model parameterization, execution, and watershed assessment at multiple temporal and spatial scales, and visualization of model simulation results (Daniel et al. 2011). Current outputs generated through use of the AGWA tool are runoff (volumes and peaks) and sediment yield, plus nitrogen and phosphorus with the SWAT model. Simulations were parameterized using a 10m DEM and derived flow direction and accumulation, the modified STATSGO soils, the seven precipitation stations in Table 5, and the ten land cover datasets produced by combining the NLCD/NALC dataset (Table 2) with the decadal ICLUS datasets. AGWA facilitates the identification of areas more susceptible/sensitive to environmental degradation and also areas for potential mitigation or enhancement by mapping spatially distributed modeling results back onto the watershed.

Results

All scenarios resulted in an increase to the Human Use Index (HUI) metric averaged over the entire watershed. 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". The ICLUS A2 scenario resulted in the largest increase of the HUI, 2.21% in year 2100 for the entire watershed (see Figure 3 and Appendix B - Table 6).

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; scenario A2 experienced the largest percent change in surface runoff and sediment yield, 1.04% and 1.19%, respectively (see Figure 4, Figure 5, and Appendix B - Table 7 and Table 8). Percent change was calculated using the following equation:

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

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.

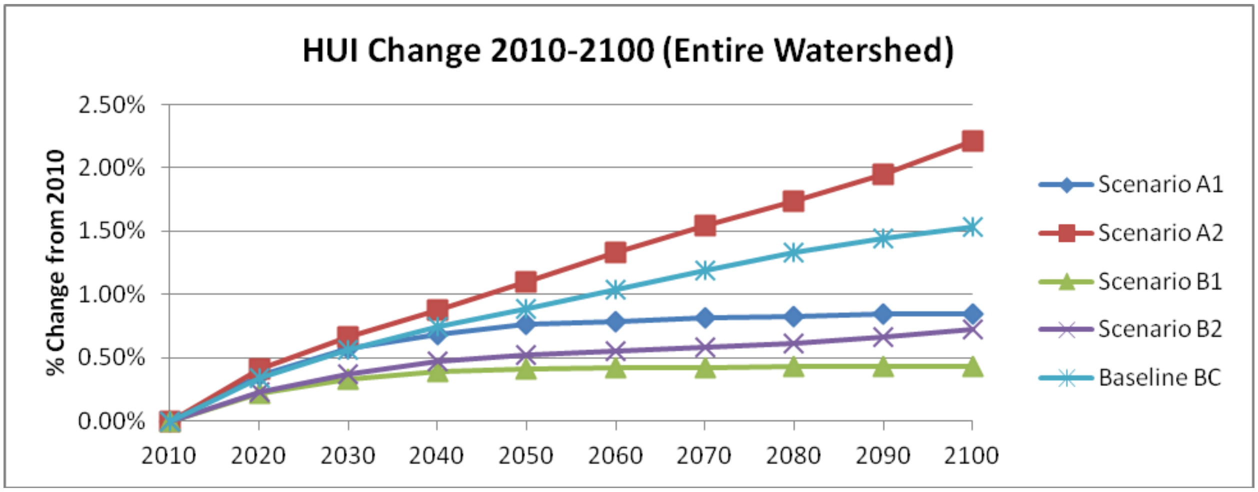


Figure 3: Watershed Average Human Use Index (HUI) for All Scenarios.

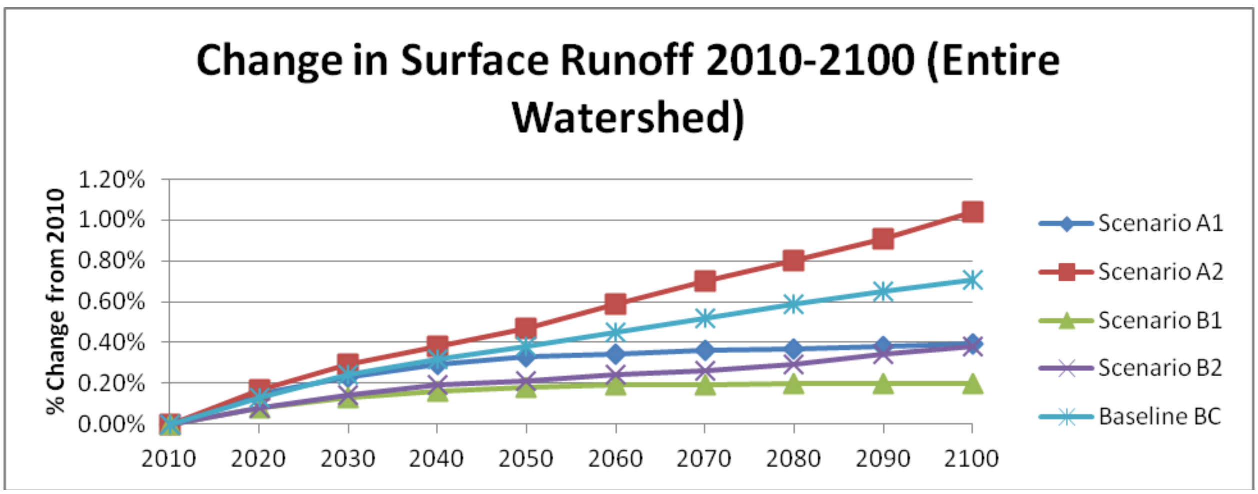


Figure 4: Watershed Average Percent Change in Surface Runoff for All Scenarios.

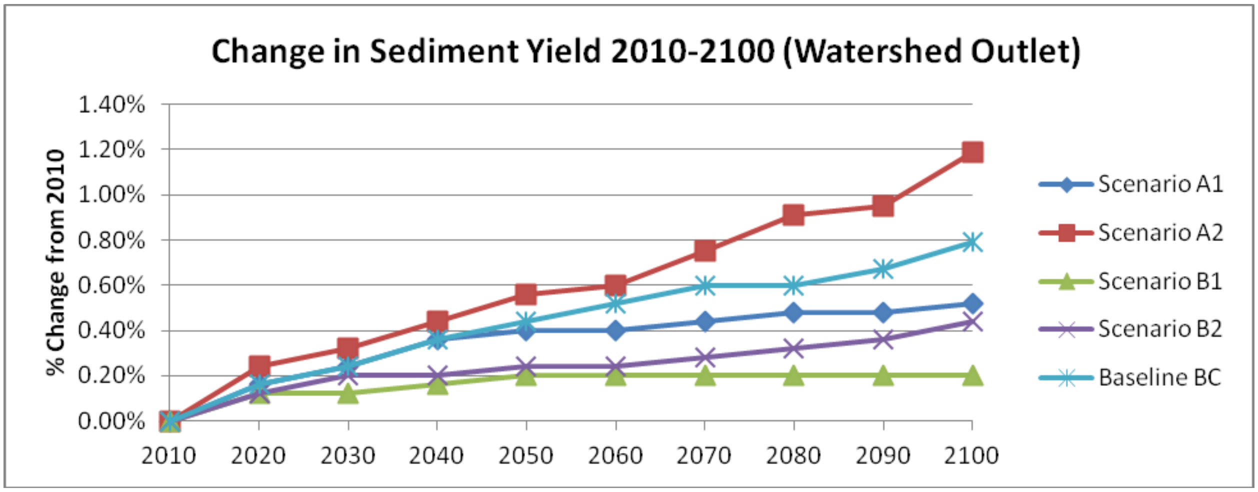


Figure 5: Watershed Average Percent Change in Sediment Yield for All Scenarios.

In contrast to the relatively low percent change at the whole watershed scale, notably higher results were seen in some subwatersheds. In scenario A2, the scenario with the most population growth, one subwatershed (#340; Figure 9), resulted in a much higher increase of up to 13.96% in the HUI in year 2100 (subwatershed #340; Figure 6 and Appendix B - Table 6). This contrast is indicative of the nature of the localized growth in the San Pedro Watershed, where development is limited by land ownership as a large percentage of the watershed consists of public lands (BLM, National Forest, Indian Reservation, National Parks, Military, State Trust, etc.). Similarly to the greater increase in the HUI at the subwatershed level, subwatershed #340 experienced greater changes than seen for the entire watershed with a 4.9% and 7.39% increase in surface runoff and sediment yield, respectively (see Figure 7, Figure 8, and Appendix B - Table 7 and Table 8).

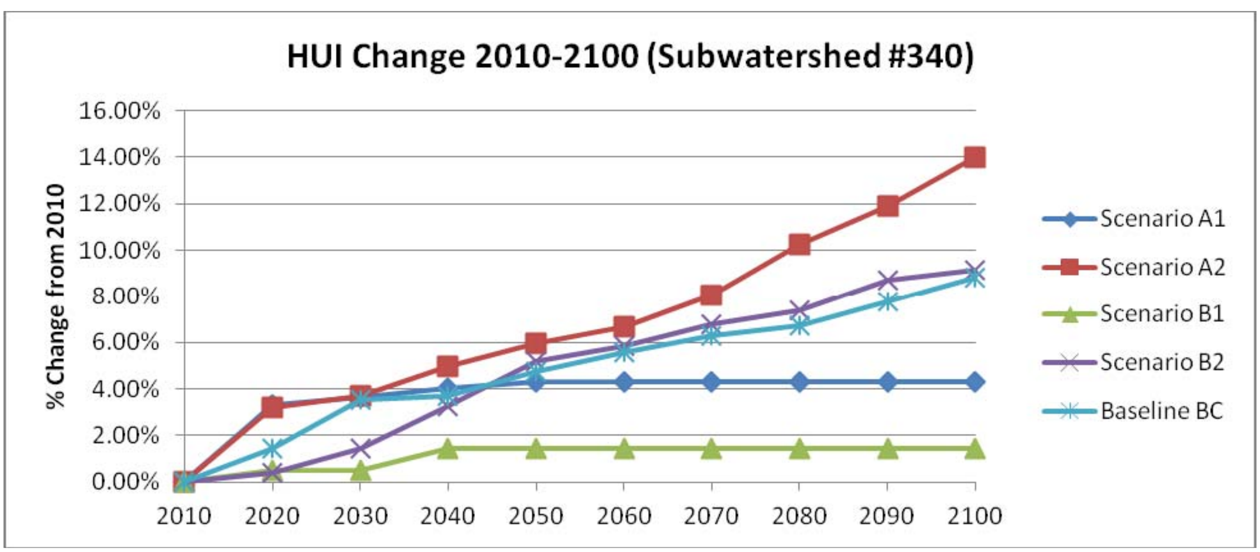


Figure 6: Subwatershed #340 Average Human Use Index (HUI) for All Scenarios.

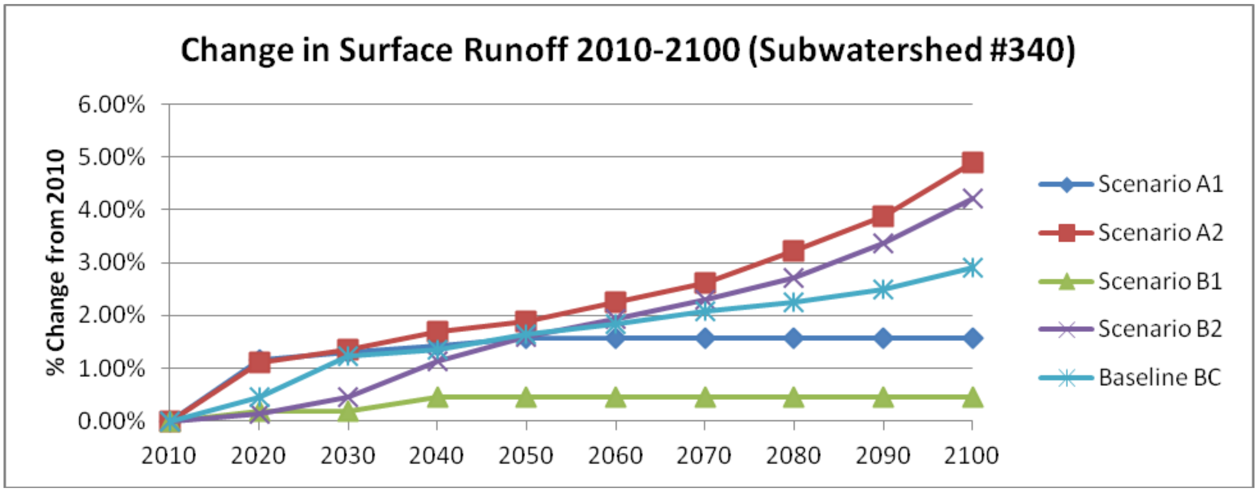


Figure 7: Subwatershed #340 Average Percent Change in Surface Runoff for All Scenarios.

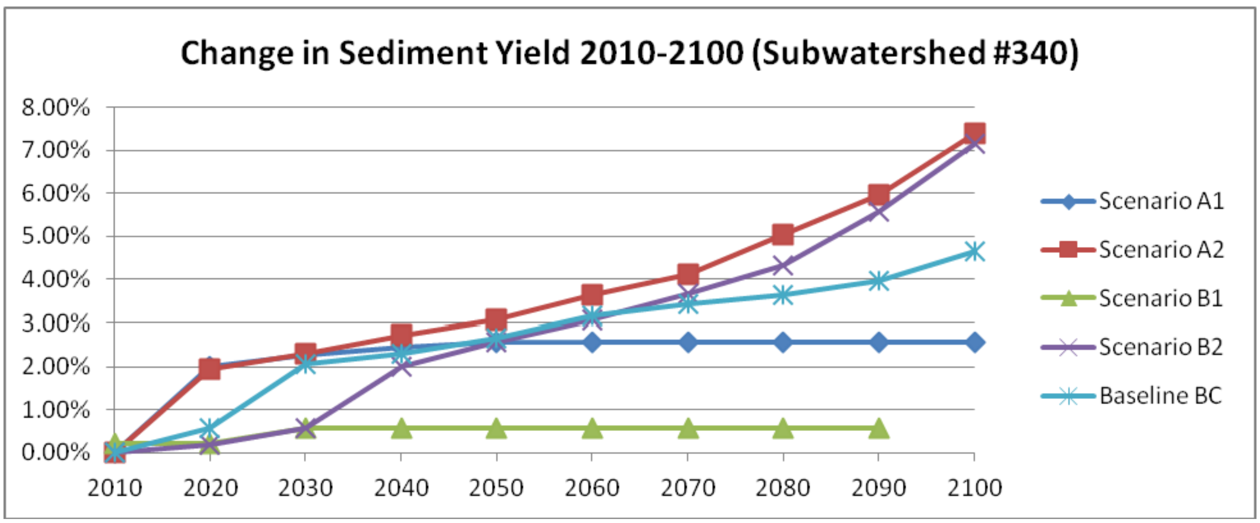


Figure 8: Subwatershed #340 Average Percent Change in Sediment Yield for All Scenarios.

Figure 9 highlights subwatersheds #340 and #341 and the percent change in surface runoff between 2010 and 2100 for scenarios A1 and A2. Subwatersheds #340 and #341 represent the lower (#340) and upper (#341) divisions of Walnut Gulch, a long-term experimental watershed operated by the USDA Agricultural Service near Tombstone, AZ. Scenarios A1 and A2 have different growth characteristics, and though scenario A2 has a much larger population than A1 in 2100, the percent change in surface runoff depicted in the figure is unexpected because scenario A1 has a higher percent change than scenario A2. Specifically, though the absolute change in surface runoff for scenario A2 is larger than the absolute change in surface runoff for scenario A1 (bottom of Figure 9), the change occurs on a larger area resulting in an explicit percent change that is smaller for scenario A2 than scenario A1 (top of Figure 9). The explicit percent change 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. Explicit percent change emphasizes that local change may be much greater than average watershed or even average subwatershed percent change can describe.

Figure 10 through Figure 14 (and Tables 9 through 13 in Appendix C) depict the percent change of HUI, channel sediment yield, and subwatershed surface runoff from 2010 to 2100 for each of the 5 ICLUS scenarios. The changes in HUI relate well to the changes in sediment yield and surface runoff. The figures show the impact of growth locally on one level with the subwatersheds and in greater detail with the explicit percent change in the growth areas in contrast to averaging the impacts over the entire watershed as presented in Table 7 and Table 8.

Figure 9: Subwatersheds #340 and #341 for Scenarios A1 and A2 from 2010 to 2100 depict 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).

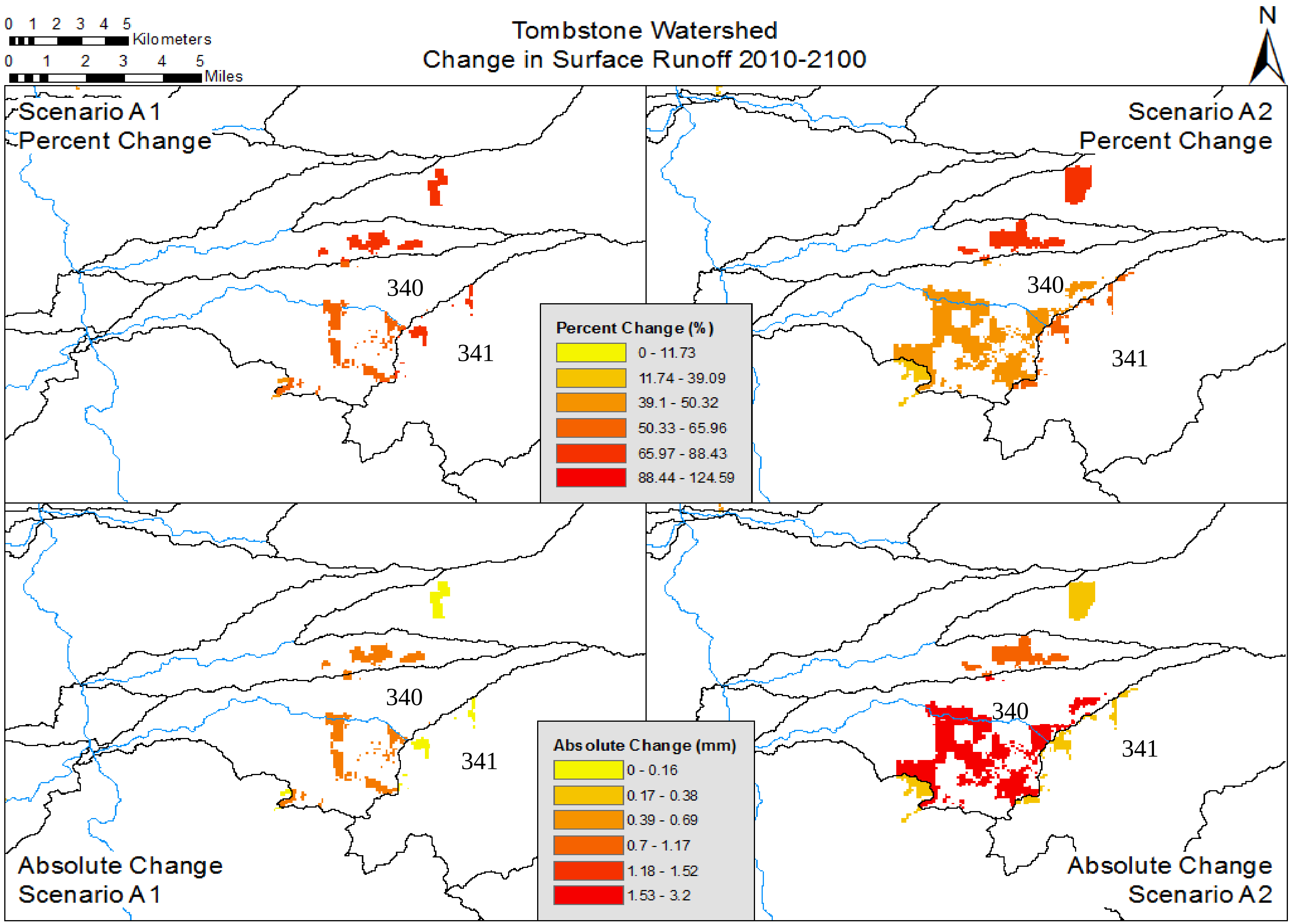


Figure 10: Change in Human Use Index (HUI), Sediment Yield, and Surface Runoff (Both Average and Explicit) in Percent from 2010 to 2100 for Scenario A1.

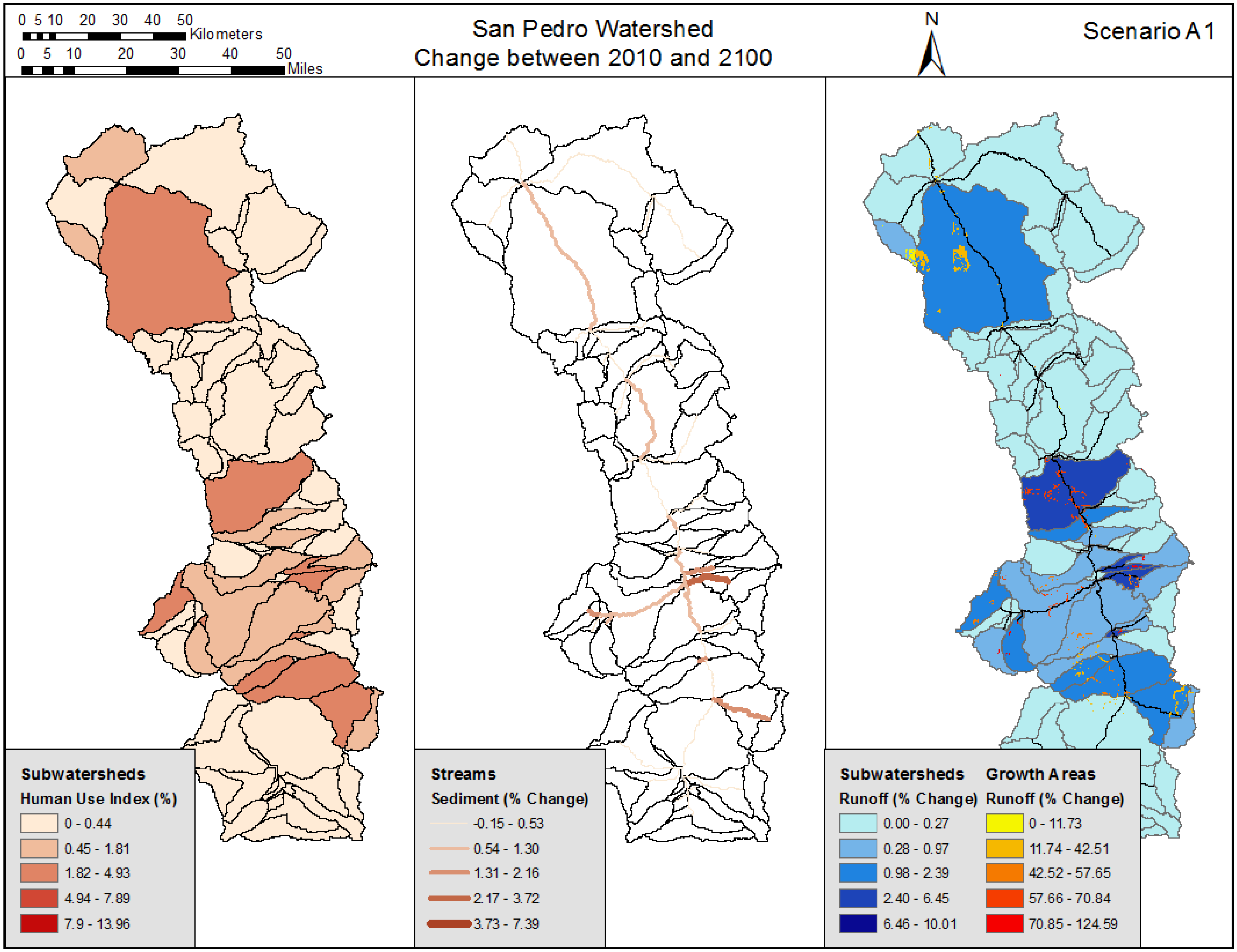


Figure 11: Change in Human Use Index (HUI), Sediment Yield, and Surface Runoff (Both Average and Explicit) in Percent from 2010 to 2100 for Scenario A2.

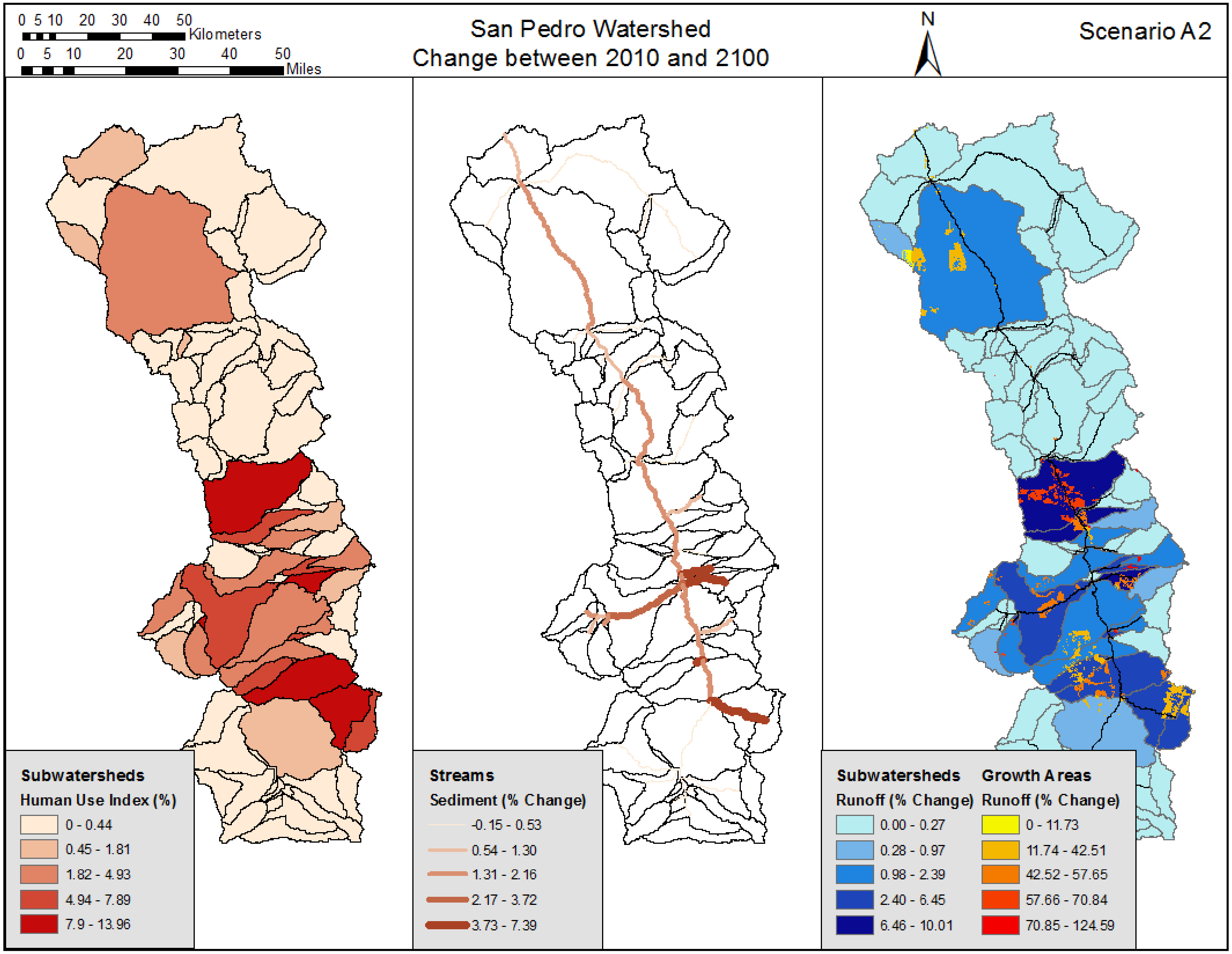


Figure 12: Change in Human Use Index (HUI), Sediment Yield, and Surface Runoff (Both Average and Explicit) in Percent from 2010 to 2100 for Scenario B1.

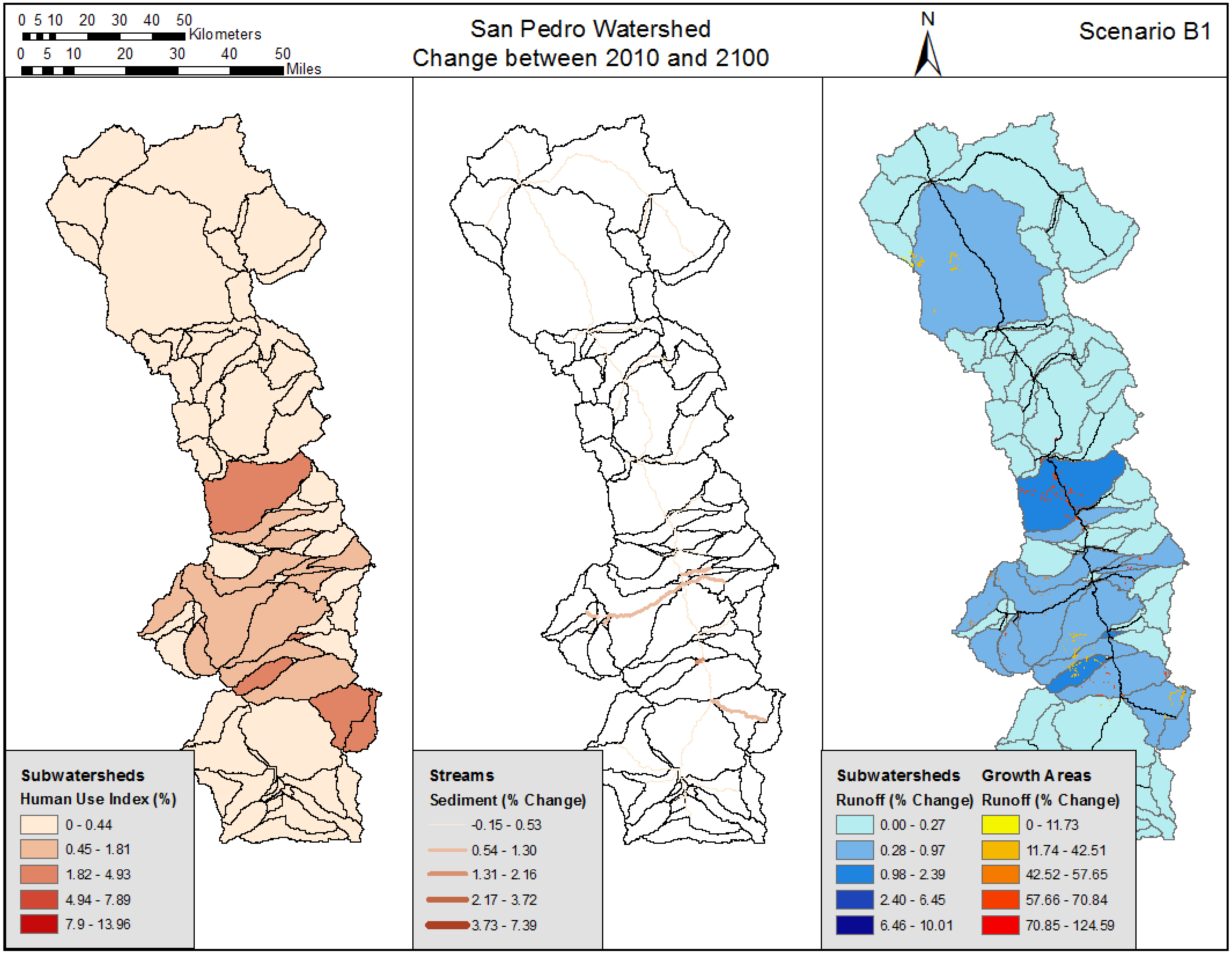


Figure 13: Change in Human Use Index (HUI), Sediment Yield, and Surface Runoff (Both Average and Explicit) in Percent from 2010 to 2100 for Scenario B2.

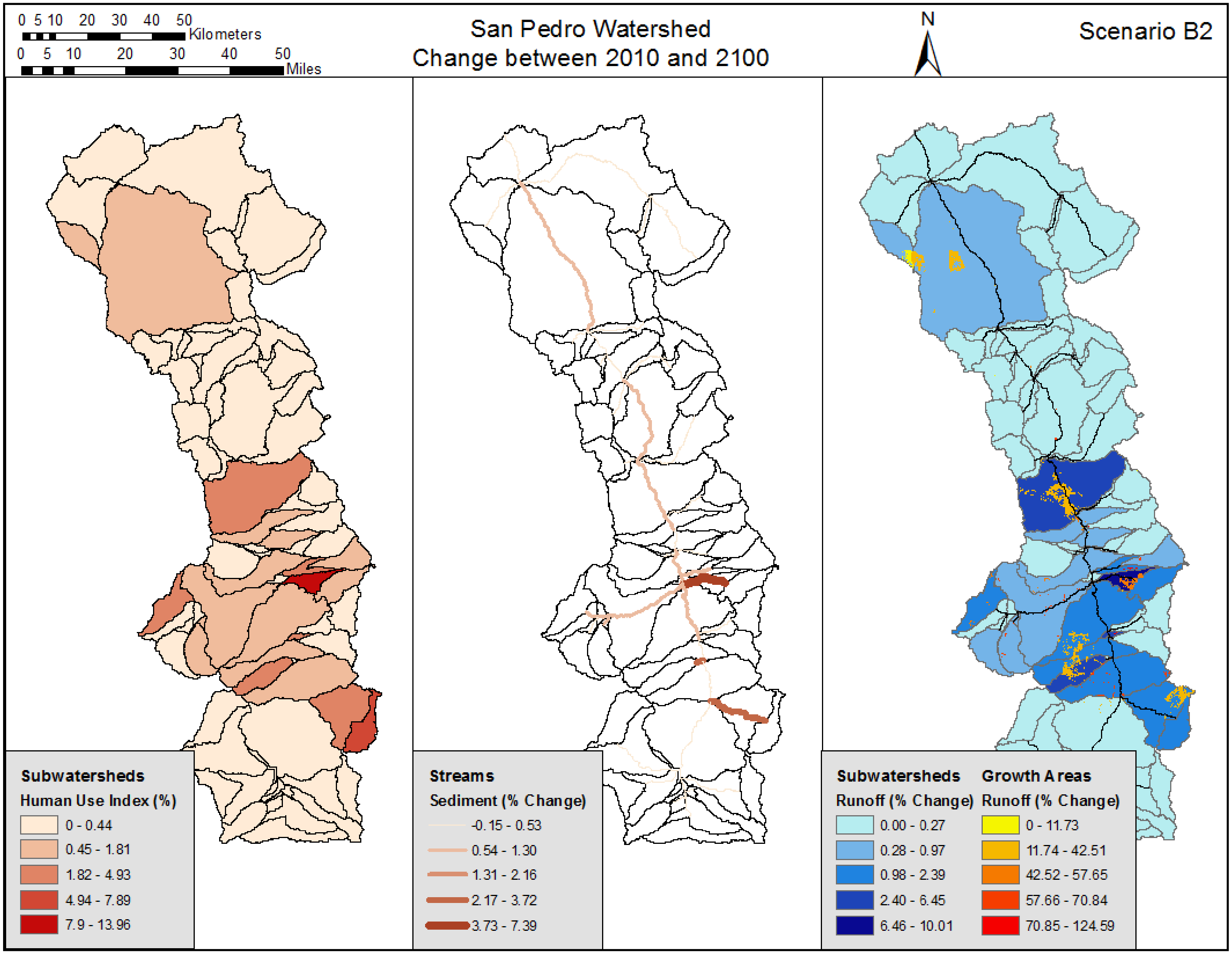
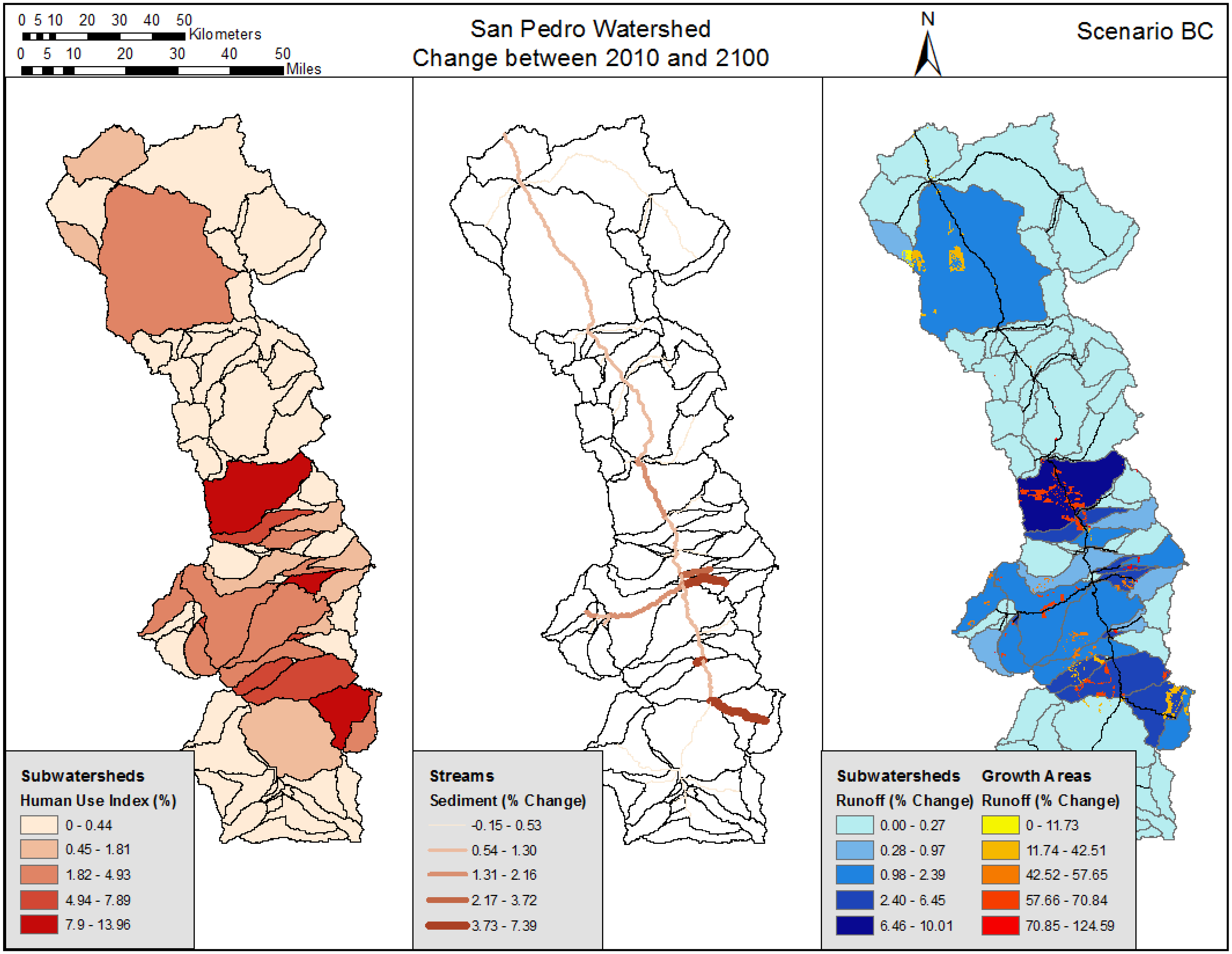


Figure 14: Change in Human Use Index (HUI), Sediment Yield, and Surface Runoff (Both Average and Explicit) in Percent from 2010 to 2100 for Baseline BC.



Discussion

The results produced by the AGWA-SWAT modeling represent a qualitative assessment of anticipated hydrologic change resulting from the ICLUS A1, A2, B1, B2, and BC scenarios. Historical rainfall and climate data are used to drive the SWAT model, so anticipated climate change is not accounted for in the results, although climate change may amplify or reduce the results presented here. Quantitative assessments of anticipated hydrologic impacts resulting from the ICLUS scenarios would require calibration for the baseline (2010) for each scenario and additional information to parameterize future decades, including but not limited to the design and placement of flood mitigation measures (detention basins, riparian buffers, water harvesting, recharge wells, open space infiltration galleries, etc.) that would be a required component of any future development.

The methodology presented herein uses HUI as an easily quantifiable metric for land cover change resulting from urban growth; however it does not distinguish between different types of human use. Different types of human use, ranging from "Developed, Open Space" to "Developed, High Intensity" to "Cultivated Crops" have different hydrologic properties associated with them, so despite the observed relationship between increasing HUI and increasing surface runoff and sediment yield in the results, HUI cannot be used as a surrogate for actual hydrologic modeling, which more closely captures the actual land cover properties and the complex interactions and feedbacks that occur across a watershed.

All the ICLUS scenarios show limited impact to the landscape at the watershed scale which is also reflected by limited hydrologic impacts at the same scale. Impacts are more pronounced at the subwatershed level where the effects of growth are not averaged out by the large percentage of undevelopable lands (i.e. BLM, Forest Service, National Monuments, etc.) in the watershed. Impacts are the highest when mapped below the subwatershed level, explicitly onto the areas that experienced change. The greatest changes in surface runoff occur in subwatersheds where the change in HUI was also greatest; accordingly, the smallest changes in surface runoff occur in areas where the change in HUI was smallest. Sediment yield in the channels is largely driven by surface runoff, so channels immediately downstream of subwatersheds with high changes in HUI and surface runoff experience the largest changes in sediment yield. The results emphasize the importance of investigating localized impacts to natural resources at appropriate scales as the impacts at the subwatershed scale and below can be much greater than at the basin scale. They also highlight the effective modulation of local changes by large undevelopable areas. Because the San Pedro Watershed is large compared to the area of developable land within it, the changes occurring on developable subwatersheds need to be examined at a larger scale (i.e. smaller drainage area). 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 effect should be addressed at the subwatershed versus basin scale for this western watershed or others like it which contain large tracts of land in the public domain, and are therefore not subject to direct urbanization impacts.

Conclusions

Hydrologic impacts of future growth through time were evaluated by using reclassified ICLUS housing density data by decade from 2010 to 2100 to represent land cover in AGWA. AGWA is a GIS tool initially developed to investigate the impacts of land cover change to hydrologic response at the watershed scale to help identify vulnerable regions and evaluate the impacts of management. AGWA allows for assessment of basin-wide changes and cumulative effects at the watershed outlet as well as more localized changes at the subwatershed level and below (explicit change mapped onto growth areas).

ICLUS datasets were used for a number of reasons, including but not limited to their availability (http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=205305); their use in a similar EPA research effort (Johnson et al. 2012); the relative simplicity of their reclassification to a product supported by AGWA; and the significant science behind the product (IPCC and SRES consistent storylines). Reclassification was necessary to convert from housing density classes to "developed" type classes in the 2006 National Land Cover Database. All land cover classes of the NLCD are supported in AGWA via look-up tables which allow for translation of land cover classes into hydrologic parameters necessary to parameterize the hydrologic models.

Changes in land cover/use under the A2 scenario result in the greatest hydrologic impacts due to a higher population growth rate and a larger natural land cover conversion rate. The results of the analyses for all scenarios over the 2010 – 2100 year period (Tables 7 and 8) indicate changes in the range of 0.2% (B1 scenario) to 1.04% (A2 scenario) on average surface runoff across the watershed, and changes in the range of 0.2% (B1 scenario) to 1.19% (A2 scenario) on sediment yield at the watershed outlet. Investigating the results at the subwatershed scale (smaller drainage areas for subwatershed #340), the changes in sediment yield are greater, ranging from 0.56% (B1 scenario) to 7.39% (A2 scenario) and the change in surface runoff ranges from 0.43% (B1 scenario) to 4.91% (A2 scenario).

Local changes to hydrology and sediment delivery at the subwatershed level and below are relevant because at those scales the impacts tend to be much more significant. Additionally, since the hydrologic impacts are tied to changes in land cover, and because the San Pedro Watershed has large amounts of land that cannot be developed, the hydrologic impacts at a watershed scale are expected to be limited. The localized impact of development found in this study may be representative for much of the western arid and semi-arid U.S., where 47.3% of the 11 coterminous western states (AZ, CA, CO, ID, MT, NV, NM, OR, UT, WA, and WY) is managed as federal public lands by BLM, FWS, NPS, USFS, and DOD (Gorte et al. 2012). Despite the constraints that limit developable areas, hydrologic changes at the watershed scale are still expected to occur.

Simulated increases in percent change of surface runoff and sediment yield closely tracked increases in the HUI metric; consequently growth and development should be moderated to prevent large increases in surface runoff and sediment yield, which could degrade water quality from sediment and pollutant transport, erode and alter the stream channel, degrade or destroy habitat, decrease biological diversity, and increase flooding. The effects of growth may be magnified or mitigated by climate change, though this is not accounted for in this analysis.

Scenario analysis is an important framework to help understand and predict potential impacts caused by decisions regarding conservation and development. For the EPA and other stakeholders, hydrologic modeling systems (e.g. AGWA) integrated with internally-consistent national scenario spatial data (i.e. ICLUS) provide an important set of tools that can help inform land use planning and permitting, mitigation, restoration, and enforcement strategies.

Appendix A

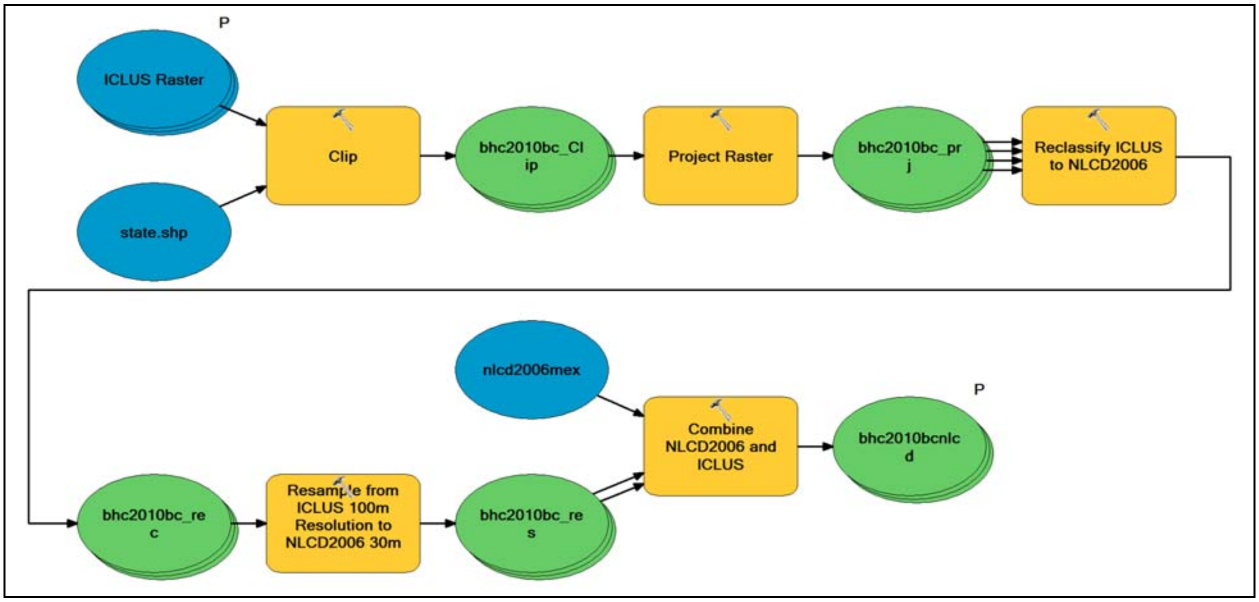


Figure 15. ArcMap Geoprocessing Model that Clipped, Projected, and Reclassified the ICLUS Data into Classified Land Cover for use in AGW.

Appendix B

Table 6: Change in Human Use Index over Time.

	HUI Base	Change in Human Use Index from base								
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Subwatershed #340										
Scenario A1	14.69%	3.32%	3.66%	4.00%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%
Scenario A2	14.69%	3.23%	3.72%	4.98%	5.97%	6.67%	8.07%	10.22%	11.92%	13.96%
Scenario B1	14.69%	0.48%	0.49%	1.44%	1.44%	1.44%	1.44%	1.44%	1.44%	1.44%
Scenario B2	14.69%	0.40%	1.44%	3.28%	5.19%	5.87%	6.76%	7.38%	8.70%	9.12%
Baseline BC	14.69%	1.44%	3.56%	3.72%	4.72%	5.56%	6.28%	6.74%	7.77%	8.84%
Watershed										
Scenario A1	5.23%	0.36%	0.57%	0.69%	0.76%	0.79%	0.81%	0.83%	0.84%	0.85%
Scenario A2	5.09%	0.41%	0.66%	0.88%	1.10%	1.33%	1.54%	1.73%	1.95%	2.21%
Scenario B1	5.15%	0.22%	0.33%	0.39%	0.41%	0.42%	0.43%	0.43%	0.43%	0.43%
Scenario B2	5.09%	0.23%	0.37%	0.47%	0.52%	0.55%	0.58%	0.61%	0.66%	0.73%
Baseline BC	5.12%	0.34%	0.57%	0.74%	0.89%	1.04%	1.19%	1.33%	1.44%	1.54%

Table 7: Change in Surface Runoff over Time.

	Surface Runoff Base	Percent Change in Surface Runoff from Base								
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Subwatershed #340 Outlet										
Scenario A1	19.4 mm	1.18%	1.32%	1.45%	1.53%	1.53%	1.53%	1.53%	1.53%	1.53%
Scenario A2	19.4 mm	1.13%	1.36%	1.67%	1.94%	2.25%	2.61%	3.25%	3.92%	4.91%
Scenario B1	19.4 mm	0.17%	0.17%	0.43%	0.43%	0.43%	0.43%	0.43%	0.43%	0.43%
Scenario B2	19.4 mm	0.13%	0.43%	1.18%	1.61%	1.94%	2.38%	2.74%	3.49%	4.30%
Baseline BC	19.4 mm	0.43%	1.22%	1.36%	1.62%	1.85%	2.08%	2.25%	2.47%	2.93%
Watershed Average										
Scenario A1	42.98 mm	0.15%	0.23%	0.29%	0.33%	0.34%	0.36%	0.37%	0.38%	0.39%
Scenario A2	42.95 mm	0.17%	0.29%	0.38%	0.47%	0.59%	0.70%	0.80%	0.91%	1.04%
Scenario B1	42.96 mm	0.08%	0.13%	0.16%	0.18%	0.19%	0.19%	0.20%	0.20%	0.20%
Scenario B2	42.96 mm	0.08%	0.14%	0.19%	0.21%	0.24%	0.26%	0.29%	0.34%	0.38%
Baseline BC	42.96 mm	0.13%	0.24%	0.32%	0.38%	0.45%	0.52%	0.59%	0.65%	0.71%

Table 8: Change in Channel Sediment Yield over Time.

	Sediment Yield Base	Percent Change in Sediment Yield from Base								
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Subwatershed #340 Outlet										
Scenario A1	28.55 t	2%	2.28%	2.45%	2.56%	2.56%	2.56%	2.56%	2.56%	2.56%
Scenario A2	28.55 t	1.93%	2.31%	2.73%	3.08%	3.64%	4.13%	5.04%	5.95%	7.39%
Scenario B1	28.55 t	0.21%	0.21%	0.56%	0.56%	0.56%	0.56%	0.56%	0.56%	0.56%
Scenario B2	28.55 t	0.18%	0.56%	2%	2.56%	3.08%	3.68%	4.31%	5.57%	7.15%
Baseline BC	28.55 t	0.56%	2.07%	2.31%	2.66%	3.15%	3.43%	3.64%	3.96%	4.66%
Watershed Outlet										
Scenario A1	25220 t	0.16%	0.24%	0.36%	0.40%	0.40%	0.44%	0.48%	0.48%	0.52%
Scenario A2	25200 t	0.24%	0.32%	0.44%	0.56%	0.60%	0.75%	0.91%	0.95%	1.19%
Scenario B1	25210 t	0.12%	0.12%	0.16%	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%
Scenario B2	25200 t	0.12%	0.20%	0.20%	0.24%	0.24%	0.28%	0.32%	0.36%	0.44%
Baseline BC	25200 t	0.16%	0.24%	0.36%	0.44%	0.52%	0.60%	0.60%	0.67%	0.79%

Appendix C

Table 9: **Land Cover Change for Scenario A1 from Baseline 2010 to 2100.** ***(Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parenthesis are the percent change in cover type from the 2010 base case).***

Scenario A1	**Base (km^2)**	**Change from Base (km^2)**								
Land Cover Type	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Open Water	3.70	-0.05 (-1.24%)	-0.08 (-2.04%)	-0.08 (-2.09%)	-0.09 (-2.31%)	-0.09 (-2.31%)	-0.14 (-3.67%)	-0.14 (-3.89%)	-0.16 (-4.33%)	-0.18 (-4.75%)
Developed, Open Space	66.66	-2.4 (-3.61%)	-3.38 (-5.08%)	-3.77 (-5.65%)	-4.01 (-6.01%)	-4.07 (-6.11%)	-4.16 (-6.24%)	-4.17 (-6.26%)	-4.18 (-6.27%)	-4.18 (-6.27%)
Developed, Low Intensity	384.80	41.69 (10.84%)	64.09 (16.66%)	77.2 (20.06%)	85.21 (22.14%)	85.74 (22.28%)	87.07 (22.63%)	88.4 (22.97%)	85.55 (22.23%)	83.74 (21.76%)
Developed, Medium Intensity	45.80	4.17 (9.11%)	7.41 (16.19%)	8.6 (18.78%)	9.5 (20.74%)	11.77 (25.7%)	13.41 (29.28%)	13.95 (30.46%)	18.43 (40.25%)	21.31 (46.52%)
Developed, High Intensity	20.57	0.2 (0.95%)	0.35 (1.72%)	0.41 (2%)	0.41 (2%)	0.41 (2%)	0.41 (2%)	0.4 (1.96%)	0.4 (1.93%)	0.4 (1.93%)
Barren Land	46.78	-0.01 (-0.02%)	-0.07 (-0.15%)	-0.1 (-0.21%)	-0.1 (-0.22%)	-0.13 (-0.28%)	-0.32 (-0.68%)	-0.63 (-1.34%)	-0.95 (-2.02%)	-1.09 (-2.33%)
Deciduous Forest	369.00	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Evergreen Forest	767.11	-0.59 (-0.08%)	-1.11 (-0.14%)	-1.37 (-0.18%)	-1.43 (-0.19%)	-1.45 (-0.19%)	-1.45 (-0.19%)	-1.45 (-0.19%)	-1.45 (-0.19%)	-1.45 (-0.19%)
Mixed Forest	9.46	-0.01 (-0.07%)	-0.02 (-0.19%)	-0.02 (-0.19%)	-0.02 (-0.19%)	-0.02 (-0.19%)	-0.02 (-0.19%)	-0.02 (-0.19%)	-0.02 (-0.19%)	-0.02 (-0.19%)
Scrub/Shrub	9523.18	-38.54 (-0.4%)	-60.98 (-0.64%)	-73.64 (-0.77%)	-81.71 (-0.86%)	-84.33 (-0.89%)	-86.78 (-0.91%)	-88.3 (-0.93%)	-89.59 (-0.94%)	-90.48 (-0.95%)
Grasslands/Herbaceous	104.83	-1.22 (-1.17%)	-1.86 (-1.78%)	-2.25 (-2.15%)	-2.42 (-2.31%)	-2.42 (-2.31%)	-2.42 (-2.31%)	-2.42 (-2.31%)	-2.42 (-2.31%)	-2.42 (-2.31%)
Pasture/Hay	12.33	-0.17 (-1.39%)	-0.29 (-2.36%)	-0.37 (-3.01%)	-0.4 (-3.23%)	-0.4 (-3.23%)	-0.43 (-3.51%)	-0.45 (-3.63%)	-0.45 (-3.63%)	-0.45 (-3.63%)
Cultivated Crops	70.38	-2.11 (-3%)	-2.63 (-3.74%)	-2.96 (-4.21%)	-3.1 (-4.41%)	-3.11 (-4.42%)	-3.11 (-4.42%)	-3.11 (-4.42%)	-3.11 (-4.42%)	-3.11 (-4.42%)
Woody Wetlands	57.91	-0.91 (-1.57%)	-1.35 (-2.33%)	-1.57 (-2.71%)	-1.74 (-3%)	-1.81 (-3.12%)	-1.96 (-3.38%)	-1.96 (-3.38%)	-1.96 (-3.38%)	-1.96 (-3.38%)
Emergent Herbaceous Wetlands	3.90	-0.06 (-1.48%)	-0.09 (-2.42%)	-0.1 (-2.47%)	-0.11 (-2.88%)	-0.11 (-2.88%)	-0.11 (-2.88%)	-0.11 (-2.88%)	-0.11 (-2.88%)	-0.11 (-2.88%)

Table 10: **Land Cover Change for Scenario A2 from Baseline 2010 to 2100.** ***(Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parenthesis are the percent change in cover type from the 2010 base case).***

Scenario A2	Base(km^2)	Change from Base (km^2)								
Land Cover Type	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Open Water	3.74	-0.09 (-2.34%)	-0.12 (-3.14%)	-0.12 (-3.16%)	-0.12 (-3.21%)	-0.15 (-3.99%)	-0.15 (-4.09%)	-0.2 (-5.45%)	-0.23 (-6.21%)	-0.36 (-9.73%)
Developed, Open Space	67.46	-2.78 (-4.17%)	-4.16 (-6.23%)	-5 (-7.51%)	-5.54 (-8.32%)	-6.12 (-9.17%)	-6.63 (-9.95%)	-7.02 (-10.53%)	-7.66 (-11.49%)	-8.1 (-12.15%)
Developed, Low Intensity	368.85	48.74 (12.67%)	76.08 (19.77%)	99.76 (25.92%)	123.66 (32.13%)	143.26 (37.23%)	157.66 (40.97%)	164.3 (42.7%)	166.67 (43.31%)	161.1 (41.87%)
Developed, Medium Intensity	44.59	3.58 (7.82%)	7.46 (16.28%)	10.39 (22.7%)	13.9 (30.34%)	22 (48.04%)	33.38 (72.89%)	50.73 (110.77%)	75.05 (163.88%)	112.34 (245.29%)
Developed, High Intensity	20.59	0.14 (0.66%)	0.31 (1.48%)	0.37 (1.8%)	0.4 (1.95%)	0.41 (1.99%)	0.43 (2.1%)	0.52 (2.53%)	0.57 (2.77%)	0.78 (3.81%)
Barren Land	46.83	-0.06 (-0.13%)	-0.12 (-0.25%)	-0.16 (-0.35%)	-0.17 (-0.37%)	-0.17 (-0.37%)	-0.2 (-0.43%)	-0.44 (-0.94%)	-1 (-2.15%)	-1.73 (-3.69%)
Deciduous Forest	369.00	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Evergreen Forest	767.34	-0.61 (-0.08%)	-1.25 (-0.16%)	-1.65 (-0.22%)	-1.99 (-0.26%)	-2.74 (-0.36%)	-3.56 (-0.46%)	-4.03 (-0.53%)	-4.5 (-0.59%)	-4.7 (-0.61%)
Mixed Forest	9.46	0 (-0.02%)	-0.02 (-0.19%)	-0.02 (-0.19%)	-0.05 (-0.49%)	-0.05 (-0.51%)	-0.06 (-0.62%)	-0.11 (-1.13%)	-0.13 (-1.32%)	-0.13 (-1.34%)
Scrub/Shrub	9538.10	-43.96 (-0.46%)	-70.78 (-0.74%)	-94.06 (-0.99%)	-118 (-1.24%)	-142.37 (-1.5%)	-165.29 (-1.74%)	-186.31 (-1.96%)	-209.77 (-2.2%)	-238.25 (-2.5%)
Grasslands/Herbaceous	105.03	-1.2 (-1.15%)	-2.06 (-1.96%)	-2.93 (-2.8%)	-3.53 (-3.37%)	-4.12 (-3.93%)	-4.54 (-4.33%)	-4.86 (-4.63%)	-5.14 (-4.91%)	-5.65 (-5.39%)
Pasture/Hay	12.35	-0.16 (-1.29%)	-0.31 (-2.47%)	-0.42 (-3.38%)	-0.77 (-6.2%)	-1.35 (-10.96%)	-1.78 (-14.4%)	-2.53 (-20.53%)	-3.44 (-27.88%)	-4.04 (-32.73%)
Cultivated Crops	70.90	-2.4 (-3.42%)	-3.31 (-4.7%)	-4.02 (-5.71%)	-5.06 (-7.19%)	-5.63 (-8%)	-6.24 (-8.86%)	-7.03 (-9.99%)	-7.38 (-10.49%)	-8.22 (-11.68%)
Woody Wetlands	58.23	-1.08 (-1.86%)	-1.6 (-2.77%)	-1.98 (-3.42%)	-2.53 (-4.36%)	-2.79 (-4.81%)	-2.81 (-4.85%)	-2.81 (-4.86%)	-2.82 (-4.87%)	-2.84 (-4.91%)
Emergent Herbaceous Wetlands	3.94	-0.11 (-2.75%)	-0.13 (-3.3%)	-0.16 (-4.01%)	-0.2 (-5.03%)	-0.2 (-5.05%)	-0.21 (-5.47%)	-0.21 (-5.47%)	-0.21 (-5.47%)	-0.21 (-5.47%)

Table 11: Land Cover Change for Scenario B1 from Baseline 2010 to 2100. ***(Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parenthesis are the percent change in cover type from the 2010 base case).***

Scenario B1	Base (km^2)	Change from Base (km^2)								
Land Cover Type	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Open Water	3.70	0 (0%)	-0.01 (-0.39%)	-0.01 (-0.39%)	-0.01 (-0.39%)	-0.01 (-0.39%)	-0.01 (-0.39%)	-0.01 (-0.39%)	-0.01 (-0.39%)	-0.01 (-0.39%)
Developed, Open Space	67.09	-1.41 (-2.12%)	-1.97 (-2.96%)	-2.3 (-3.45%)	-2.37 (-3.56%)	-2.37 (-3.56%)	-2.39 (-3.58%)	-2.39 (-3.58%)	-2.4 (-3.61%)	-2.4 (-3.61%)
Developed, Low Intensity	376.05	24.24 (6.3%)	36.5 (9.49%)	41.35 (10.75%)	42.38 (11.01%)	42.56 (11.06%)	42.38 (11.01%)	42.1 (10.94%)	41.28 (10.73%)	40.88 (10.62%)
Developed, Medium Intensity	45.25	2.94 (6.43%)	5.17 (11.28%)	7.59 (16.58%)	9.54 (20.82%)	10.27 (22.42%)	10.92 (23.85%)	11.34 (24.76%)	12.47 (27.24%)	12.88 (28.12%)
Developed, High Intensity	20.55	0.15 (0.71%)	0.22 (1.06%)	0.36 (1.75%)	0.37 (1.79%)	0.39 (1.91%)	0.39 (1.91%)	0.39 (1.91%)	0.39 (1.91%)	0.39 (1.91%)
Barren Land	46.78	0 (0%)	-0.01 (-0.01%)	-0.03 (-0.06%)	-0.04 (-0.08%)	-0.04 (-0.09%)	-0.04 (-0.09%)	-0.04 (-0.09%)	-0.04 (-0.09%)	-0.04 (-0.09%)
Deciduous Forest	369.00	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Evergreen Forest	767.27	-0.51 (-0.07%)	-0.61 (-0.08%)	-0.94 (-0.12%)	-1.35 (-0.18%)	-1.52 (-0.2%)	-1.55 (-0.2%)	-1.55 (-0.2%)	-1.55 (-0.2%)	-1.55 (-0.2%)
Mixed Forest	9.46	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)
Scrub/Shrub	9531.24	-22.94 (-0.24%)	-34.96 (-0.37%)	-41.44 (-0.44%)	-43.48 (-0.46%)	-44.16 (-0.46%)	-44.6 (-0.47%)	-44.73 (-0.47%)	-45.03 (-0.47%)	-45.03 (-0.47%)
Grasslands/Herbaceous	105.00	-0.72 (-0.69%)	-1.34 (-1.28%)	-1.42 (-1.35%)	-1.45 (-1.38%)	-1.46 (-1.39%)	-1.46 (-1.39%)	-1.46 (-1.39%)	-1.46 (-1.39%)	-1.46 (-1.39%)
Pasture/Hay	12.34	-0.04 (-0.36%)	-0.12 (-0.95%)	-0.12 (-0.99%)	-0.12 (-0.99%)	-0.12 (-0.99%)	-0.12 (-0.99%)	-0.12 (-0.99%)	-0.12 (-0.99%)	-0.12 (-0.99%)
Cultivated Crops	70.69	-1.11 (-1.58%)	-1.94 (-2.76%)	-2.03 (-2.89%)	-2.24 (-3.18%)	-2.27 (-3.22%)	-2.27 (-3.22%)	-2.27 (-3.22%)	-2.27 (-3.22%)	-2.27 (-3.22%)
Woody Wetlands	58.06	-0.52 (-0.89%)	-0.82 (-1.41%)	-0.9 (-1.55%)	-1.09 (-1.89%)	-1.13 (-1.95%)	-1.13 (-1.95%)	-1.13 (-1.95%)	-1.13 (-1.95%)	-1.13 (-1.95%)
Emergent Herbaceous Wetlands	3.93	-0.07 (-1.73%)	-0.1 (-2.65%)	-0.11 (-2.75%)	-0.12 (-3.09%)	-0.13 (-3.3%)	-0.13 (-3.3%)	-0.13 (-3.3%)	-0.13 (-3.3%)	-0.13 (-3.3%)

Table 12: Land Cover Change for Scenario B2 from Baseline 2010 to 2100. ***(Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parenthesis are the percent change in cover type from the 2010 base case).***

Scenario B2	**Base (km^2)**	**Change from Base (km^2)**								
Land Cover Type	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Open Water	3.72	-0.02 (-0.49%)	-0.03 (-0.88%)	-0.04 (-0.97%)	-0.04 (-1.02%)	-0.04 (-1.02%)	-0.09 (-2.31%)	-0.09 (-2.31%)	-0.23 (-6.08%)	-0.25 (-6.77%)
Developed, Open Space	67.57	-1.6 (-2.4%)	-2.42 (-3.63%)	-2.98 (-4.46%)	-3.14 (-4.71%)	-3.27 (-4.9%)	-3.32 (-4.98%)	-3.46 (-5.19%)	-3.64 (-5.47%)	-3.78 (-5.67%)
Developed, Low Intensity	368.84	26.48 (6.88%)	42.18 (10.96%)	50.07 (13.01%)	52.95 (13.76%)	50.28 (13.07%)	41.4 (10.76%)	23.97 (6.23%)	-0.28 (-0.07%)	-17.79 (-4.62%)
Developed, Medium Intensity	44.43	3.14 (6.86%)	5.65 (12.33%)	9.64 (21.06%)	12.75 (27.83%)	19.07 (41.64%)	31.1 (67.9%)	52.38 (114.38%)	82.56 (180.26%)	107.91 (235.63%)
Developed, High Intensity	20.55	0.12 (0.58%)	0.2 (0.98%)	0.44 (2.15%)	0.51 (2.49%)	0.73 (3.54%)	0.85 (4.11%)	0.94 (4.57%)	0.96 (4.65%)	1.04 (5.07%)
Barren Land	46.78	0 (0%)	-0.01 (-0.01%)	-0.03 (-0.07%)	-0.04 (-0.09%)	-0.08 (-0.16%)	-0.14 (-0.3%)	-0.18 (-0.39%)	-0.18 (-0.39%)	-0.24 (-0.52%)
Deciduous Forest	369.00	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Evergreen Forest	767.37	-0.52 (-0.07%)	-0.7 (-0.09%)	-0.92 (-0.12%)	-1.37 (-0.18%)	-1.69 (-0.22%)	-1.71 (-0.22%)	-1.73 (-0.23%)	-1.75 (-0.23%)	-1.81 (-0.24%)
Mixed Forest	9.46	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)	-0.01 (-0.07%)
Scrub/Shrub	9537.61	-24.48 (-0.26%)	-39.46 (-0.41%)	-50.14 (-0.53%)	-54.95 (-0.58%)	-58.25 (-0.61%)	-61.27 (-0.64%)	-64.97 (-0.68%)	-70.43 (-0.74%)	-77.87 (-0.82%)
Grasslands/Herbaceous	105.14	-0.71 (-0.68%)	-1.48 (-1.41%)	-1.72 (-1.64%)	-1.76 (-1.68%)	-1.83 (-1.74%)	-1.88 (-1.8%)	-1.91 (-1.83%)	-1.98 (-1.89%)	-1.99 (-1.9%)
Pasture/Hay	12.37	-0.06 (-0.51%)	-0.15 (-1.22%)	-0.18 (-1.44%)	-0.18 (-1.47%)	-0.18 (-1.47%)	-0.18 (-1.47%)	-0.18 (-1.47%)	-0.22 (-1.81%)	-0.22 (-1.81%)
Cultivated Crops	71.41	-1.67 (-2.38%)	-2.68 (-3.81%)	-2.93 (-4.16%)	-3.21 (-4.56%)	-3.22 (-4.58%)	-3.22 (-4.58%)	-3.23 (-4.6%)	-3.26 (-4.63%)	-3.41 (-4.85%)
Woody Wetlands	58.22	-0.58 (-1.01%)	-0.98 (-1.68%)	-1.1 (-1.9%)	-1.37 (-2.36%)	-1.37 (-2.36%)	-1.37 (-2.36%)	-1.38 (-2.39%)	-1.38 (-2.39%)	-1.43 (-2.47%)
Emergent Herbaceous Wetlands	3.95	-0.09 (-2.26%)	-0.12 (-3.07%)	-0.13 (-3.35%)	-0.15 (-3.83%)	-0.15 (-3.83%)	-0.15 (-3.83%)	-0.15 (-3.83%)	-0.15 (-3.83%)	-0.15 (-3.83%)

Table 13: Land Cover Change for Baseline BC from Baseline 2010 to 2100. ***(Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parenthesis are the percent change in cover type from the 2010 base case).***

Scenario BC	Base (km^2)	Change from Base (km^2)								
Land Cover Type	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Open Water	3.74	-0.07 (-2%)	-0.1 (-2.82%)	-0.12 (-3.16%)	-0.12 (-3.16%)	-0.13 (-3.43%)	-0.15 (-3.99%)	-0.15 (-3.99%)	-0.21 (-5.57%)	-0.23 (-6.11%)
Developed, Open Space	67.28	-2.28 (-3.43%)	-3.44 (-5.16%)	-4.29 (-6.44%)	-4.83 (-7.25%)	-5.24 (-7.87%)	-5.52 (-8.28%)	-5.87 (-8.8%)	-6.2 (-9.29%)	-6.39 (-9.59%)
Developed, Low Intensity	372.25	40.45 (10.51%)	65.79 (17.1%)	84.62 (21.99%)	100.71 (26.17%)	117.86 (30.63%)	133.25 (34.63%)	144.52 (37.56%)	152.91 (39.74%)	153.97 (40.01%)
Developed, Medium Intensity	44.77	3.04 (6.63%)	5.81 (12.68%)	8.37 (18.27%)	10.28 (22.45%)	12.07 (26.36%)	14.3 (31.22%)	20.08 (43.85%)	25.51 (55.69%)	36.23 (79.1%)
Developed, High Intensity	20.56	0.16 (0.76%)	0.21 (1.03%)	0.34 (1.67%)	0.39 (1.91%)	0.4 (1.96%)	0.42 (2.06%)	0.44 (2.13%)	0.43 (2.11%)	0.43 (2.08%)
Barren Land	46.83	-0.06 (-0.13%)	-0.09 (-0.2%)	-0.13 (-0.27%)	-0.16 (-0.35%)	-0.17 (-0.36%)	-0.17 (-0.36%)	-0.23 (-0.49%)	-0.48 (-1.03%)	-1.02 (-2.18%)
Deciduous Forest	369.00	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Evergreen Forest	767.33	-0.53 (-0.07%)	-1.03 (-0.13%)	-1.32 (-0.17%)	-1.74 (-0.23%)	-1.98 (-0.26%)	-2.52 (-0.33%)	-2.84 (-0.37%)	-3.09 (-0.4%)	-3.54 (-0.46%)
Mixed Forest	9.46	0 (-0.02%)	-0.02 (-0.19%)	-0.02 (-0.19%)	-0.04 (-0.37%)	-0.05 (-0.49%)	-0.05 (-0.51%)	-0.05 (-0.51%)	-0.05 (-0.51%)	-0.06 (-0.62%)
Scrub/Shrub	9534.95	-36.53 (-0.38%)	-60.7 (-0.64%)	-79.33 (-0.83%)	-95.08 (-1%)	-111.86 (-1.17%)	-127.87 (-1.34%)	-143.4 (-1.51%)	-155.34 (-1.63%)	-165.19 (-1.73%)
Grasslands/Herbaceous	104.96	-1.19 (-1.13%)	-1.78 (-1.7%)	-2.4 (-2.29%)	-2.8 (-2.67%)	-3.31 (-3.15%)	-3.5 (-3.34%)	-3.85 (-3.67%)	-4.18 (-3.98%)	-4.32 (-4.12%)
Pasture/Hay	12.35	-0.14 (-1.11%)	-0.26 (-2.1%)	-0.34 (-2.76%)	-0.49 (-3.94%)	-0.65 (-5.28%)	-0.92 (-7.46%)	-1.15 (-9.31%)	-1.44 (-11.65%)	-1.73 (-14.03%)
Cultivated Crops	70.83	-2.02 (-2.87%)	-2.91 (-4.13%)	-3.56 (-5.06%)	-4.07 (-5.78%)	-4.73 (-6.72%)	-4.98 (-7.08%)	-5.21 (-7.4%)	-5.56 (-7.9%)	-5.83 (-8.28%)
Woody Wetlands	58.14	-0.71 (-1.23%)	-1.36 (-2.35%)	-1.67 (-2.88%)	-1.91 (-3.29%)	-2.04 (-3.52%)	-2.1 (-3.63%)	-2.12 (-3.65%)	-2.13 (-3.68%)	-2.13 (-3.69%)
Emergent Herbaceous Wetlands	3.94	-0.09 (-2.35%)	-0.12 (-3.11%)	-0.15 (-3.92%)	-0.16 (-4.15%)	-0.19 (-4.75%)	-0.19 (-4.75%)	-0.19 (-4.75%)	-0.19 (-4.75%)	-0.19 (-4.75%)

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