United States
Environmental Protection
Agency

EPA/600/R-14/328
ARS/309194
September 2014

Assessing Hydrologic Impacts of Future Land Cover Change Scenarios in the South Platte River Basin (CO, WY, & NE)

RESEARCH AND DEVELOPMENT

Assessing Hydrologic Impacts of Future Land Cover Change Scenarios in the South Platte River Basin (CO, WY, & NE)

J. E. Barlow[1], I.S. Burns[1], W.G. Kepner[2], G.S. Sidman[1], D.C. Goodrich[3], D.P. Guertin[1], and J.M. McCarthy[4]

[1]University of Arizona, School of Natural Resources and the Environment, Tucson, AZ

[2]U.S. Environmental Protection Agency, Office of Research and Development, Las Vegas, NV

[3]USDA-Agricultural Research Service, Southwest Watershed Research Center, Tucson, AZ

[4]U.S. Environmental Protection Agency, Region 8, Denver, CO

U.S. Environmental Protection Agency

Office of Research and Development

Washington, DC 20460

Acknowledgements

This project was funded through the U.S. Environmental Protection Agency (EPA) Regional Applied Research Effort (RARE) Program, which is administered by the Office of Research and Development's (ORD) Regional Science Program.

We would like to acknowledge the key reviewers of this report for their valuable suggestions. Specifically, our thanks go to Dr. W. Paul Miller, Senior Hydrologist, National Oceanic and Atmospheric Administration (NOAA), Colorado Basin River Forecast Center, Salt Lake City, UT; Dr. Britta G. Bierwagen, EPA/ORD, Global Change Research Program, National Center for Environmental Assessment, Washington, DC; and Dr. Francina Dominguez, Assistant Professor in Department of Atmospheric Sciences and co-Director of Hydrometeorology Program, University of Arizona, Tucson, AZ.

This report has been subjected to the EPA/ORD and U.S. Department of Agriculture/Agricultural Research Service (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.

Table of Contents

Acknowledgements iii
Table of Contents v
List of Figures vii
List of Tables ix
Acronyms and Abbreviations x
Abstract 1
Introduction 1
Methods 4
Project/Watershed Extent 4
Land Cover 4
Soils 8
Precipitation 8
Reservoirs 9
AGWA-SWAT Modeling 10
Results 11
Discussion 24
Conclusions 25
Appendix A 29
Appendix B 30
Appendix C 32
Appendix D 35
References 40

List of Figures

Figure 1: Location map of the study area with CFSR points for precipitation and weather generating stations for the South Platte River Basin. 3

Figure 2: Population projections for ICLUS scenarios by decade (EPA 2009). 7

Figure 3: Population projections for ICLUS scenarios by decade for counties that intersect the South Platte River Basin (ORD 2007; Appendix B - Figure 21). 7

Figure 4: Watershed Human Use Index (HUI) for all scenarios. 11

Figure 5: Watershed average percent change in average annual surface runoff for all scenarios. 12

Figure 6: Watershed average percent change in average annual sediment yield for all scenarios. 12

Figure 7: Subwatershed #340 Human Use Index (HUI) for all scenarios. 13

Figure 8: Subwatershed #340 average percent change in average annual surface runoff for all scenarios. 13

Figure 9: Subwatershed #340 average percent change in average annual sediment yield for all scenarios. 14

Figure 10: Spatial distribution of anthropogenic land use in the year 2100 under scenarios B1 and A2. 15

Figure 11: Effect of reservoirs modeled in SWAT on sediment yield at the watershed outlet and below Strontia Springs Reservoir. 16

Figure 12: Effect of reservoirs modeled in SWAT on streamflow below Strontia Springs Reservoir and at the watershed outlet. 17

Figure 13: Sediment yield within the South Platte River Basin, emphasis on the Strontia Springs Reservoir (reservoir #151) where sediment yield decreases downstream of the impoundment. Bar graph illustrates the difference in sediment yield portrayed in the map as a percentage of sediment yield flowing above Strontia Springs. 18

Figure 14: Change in Human Use Index (HUI), average annual sediment yield, and average annual surface runoff in percent from 2010 to 2100 for scenario A1. 19

Figure 15: Change in Human Use Index (HUI), average annual sediment yield, and average annual surface runoff in percent from 2010 to 2100 for scenario A2. 20

Figure 16: Change in Human Use Index (HUI), average annual sediment yield, and average annual surface runoff in percent from 2010 to 2100 for scenario B1. 21

Figure 17: Change in Human Use Index (HUI), average annual sediment yield, and average annual surface runoff in percent from 2010 to 2100 for scenario B2. 22

Figure 18: Change in Human Use Index (HUI), average annual sediment yield, and average annual surface runoff in percent from 2010 to 2100 for scenario BC. 23

Figure 19: ArcMap Geoprocessing Model that Clipped, Projected, and Reclassified the ICLUS Data into Classified Land Cover for use in AGWA. 29

Figure 20: Example of inputs used to run AGWA-SWAT. 30

Figure 21: Counties included when calculating estimated population growth by decade under different scenarios within the South Platte River Basin. 31

Figure 22: Results presented in this report represent a watershed average as well values for specific streams and subwaterwsheds. 32

List of Tables

Table 1: Summary of the types of changes of the different ICLUS scenarios (EPA 2009). 5

Table 2: Explanation of ICLUS housing density categories (EPA 2010).......... 6

Table 3: Reclassification Table for ICLUS Housing Density Classes to 2006 NLCD Land Cover Types.......... 8

Table 4: Reservoirs Included in the SWAT Modeling of the South Platte River Basin. 9

Table 5: Change in Human Use Index over Time.......... 33

Table 6: Change in Average Annual Surface Runoff over Time. 33

Table 7: Change in Channel Average Annual Sediment Yield over Time. 34

Table 8: Land Cover Change for Scenario A1 from Baseline 2010 to 2100 (*Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parentheses are the percent change in cover type from the 2010 base case*). 35

Table 9: Land Cover Change for Scenario A2 from Baseline 2010 to 2100 (*Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parentheses are the percent change in cover type from the 2010 base case*). 36

Table 10: Land Cover Change for Scenario B1 from Baseline 2010 to 2100 (*Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parentheses are the percent change in cover type from the 2010 base case*). 37

Table 11: Land Cover Change for Scenario B2 from Baseline 2010 to 2100 (*Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parentheses are the percent change in cover type from the 2010 base case*). 38

Table 12: Land Cover Change for Baseline BC from Baseline 2010 to 2100 (*Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parentheses are the percent change in cover type from the 2010 base case*). 39

Acronyms and Abbreviations

ACOE	U.S. Army Corps of Engineers
AGWA	Automated Geospatial Watershed Assessment tool
ARS	U.S.D.A Agricultural Research Service
BC	Base Case
CWA	Clean Water Act
CDSS	Colorado Decision Support System
CFSR	Climate Forecast System Re-analysis
DEM	Digital Elevation Model
DST	Decision Support Tool
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
MRLC	Multi-Resolution Land Characteristics Consortium
NED	National Elevation Dataset
NCEP	National Centers for Environmental Prediction
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
ORD	Office of Research and Development
RARE	Regional Applied Research Effort
SRES	Special Report on Emissions Scenarios
STATSGO	State Soil Geographic Data Base

SWAT	Soil and Water Assessment Tool
USDA	U.S. Department of Agriculture
USDI	U.S. Department Interior
USGS	U.S. Geological Survey

Abstract

Long-term land-use and land cover changes and their associated impacts pose critical challenges to sustaining vital hydrological ecosystem services for future generations. In this study, a methodology first developed on the San Pedro River Basin in southeastern Arizona was used to characterize potential hydrologic impacts from future urban growth scenarios through time on the South Platte River Basin. 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 tool (AGWA). The objectives of this project were to 1) expand a methodology for adapting the ICLUS data for use in AGWA as an approach to evaluate basin-wide impacts of development on streamflow runoff characteristics and water quality in a large, complex watershed, 2) present qualitative results from the application of the methodology to evaluate water scenario analyses related to a baseline condition and projected changes, and 3) discuss implications of the analysis for water resources and land management in the South Platte River Basin.

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 which 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 identify 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 ability to explore pathways of change that diverge from baseline conditions and lead to plausible future states or events. It 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 policy and management paradigms (Steinitz et al. 2003, Kepner et al. 2012, March et al. 2012). These frameworks are frequently combined with process modeling 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 draws substantial background from Burns et al. (2013) and uses the methodology first developed on the San Pedro River Basin in southeastern Arizona. The methodology integrates a widely used watershed modeling tool and national database with alternative future scenarios which are scaled to regional and local applications. Expansion of the methodology for the South Platte River Basin integrates some of the hydrologic complexities related to the modeling of water in storage in the South Platte River and its tributaries to characterize potential hydrologic impacts at different scales. This report describes the cumulative impact of housing densities parsed out at decadal intervals to the year 2100 on a hydrological ecosystem that spans from the Front Range of the Rocky Mountains to the North American Great Plains.

The U.S. Environmental Protection Agency (EPA) supports a watershed approach to resource protection that emphasizes restoration and rehabilitation of ecosystem services to enhance or maintain hydrologic function within the South Platte River Basin. In an effort to improve the ability of environmental decision makers and managers to plan and respond to potential change at the basin scale, the EPA, U.S. Department of Agriculture (USDA) Agriculture Research Service (ARS), 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 focused on the South Platte River Basin. 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. In order to understand the cumulative impact of housing development and land cover change, we will look at relative changes in surface runoff, streamflow and sediment yield across the basin.

The study area encompasses the South Platte River Basin (~61,700 km^2 or ~23,820 mi^2) from the headwaters near Fairplay, CO to the outlet defined near Sutherland, NE (Figure 1). The entirety of the South Platte River flows over 700 km (435 mi) from the headwaters in the Front Range to its confluence with the North Platte River in North Platte, NE. A complex network of water uses, land uses, and stakeholder priorities influence the quantity and quality of water that flows in the South Platte River. The South Platte River Basin is home to over 70% of Colorado's population which means water resources are allocated to their growing municipalities as well as agricultural and industrial sectors (Dennehy et al. 1993). Vegetation transitions from evergreen and deciduous forest in the Upper South Platte to range and grasslands in the Lower South Platte. High elevation, forested subwatersheds contribute a substantial amount of water resources to the river basin via snowmelt and summer precipitation (Dennehy et al. 1993).

Since the 19th century, the South Platte River has been developed in order to provide beneficial uses which include municipal water supply, agricultural water supply, water for recreation, and water for aquatic life (Eschner et al. 1983; Saunders and Lewis 2003). Spring snowmelt and heavy precipitation is stored, utilized, and most returned to the mainstem river after use via a number of canals, dams, and reservoirs throughout the watershed (Kircher and Karlinger 1983). Natural features such as riparian habitat, wetlands and marshes along the main channel and its tributaries provide essential ecosystem services in the form of erosion control, flood control, nutrient filtering, avian habitat, and aquatic habitat (Rapport et al. 1998; Strange et al. 1999; Naiman and Décamps 1997; Novitzki et al. 1997). Conservation, restoration and rehabilitation of these wetlands is a priority of the EPA and U.S. Army Corps of Engineers (ACOE); additionally constructed wetlands have been used to augment ecosystem services in recently developed areas for the purpose of flood control and water quality improvements.

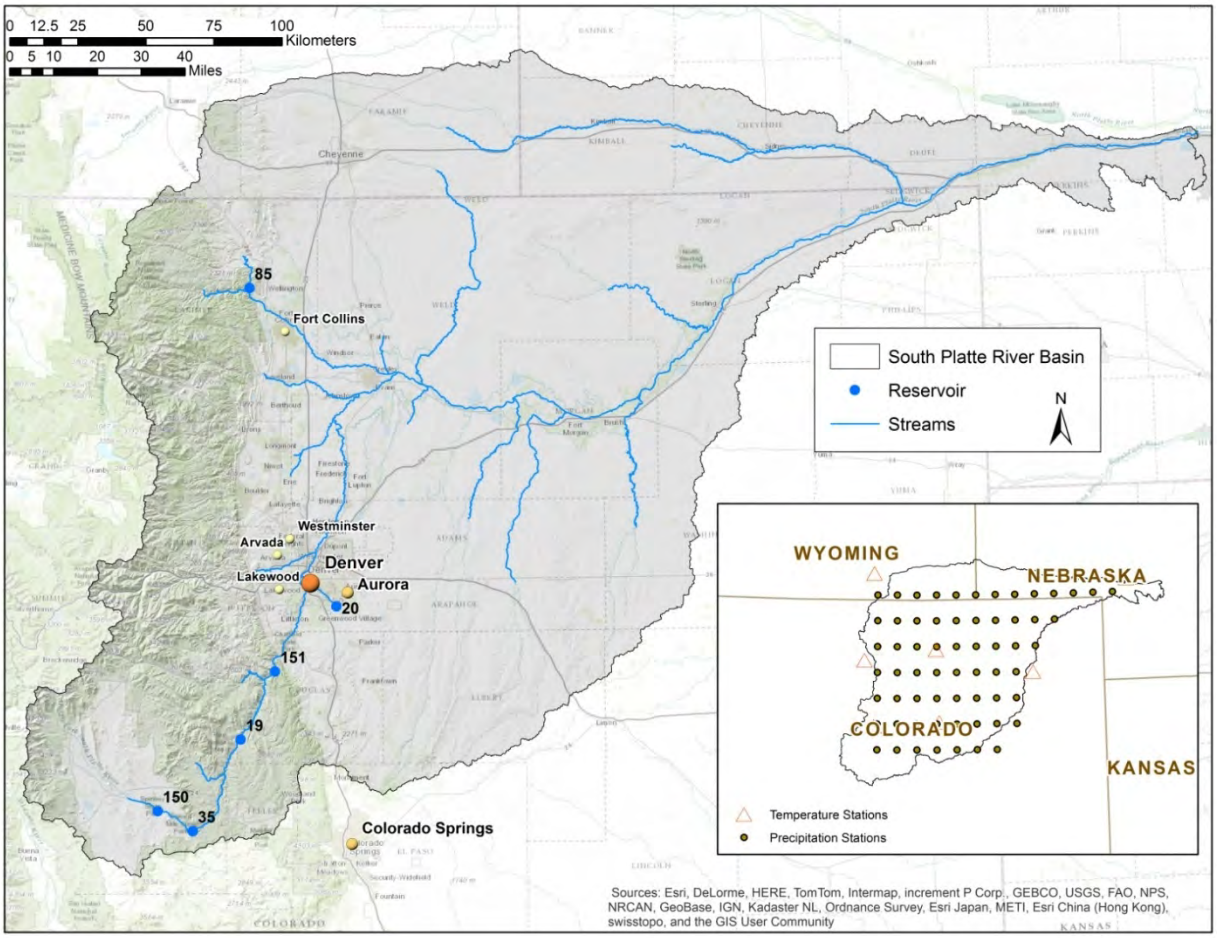

Figure 1: Location map of the study area with CFSR points for precipitation and weather generating stations for the South Platte River Basin.

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 tool (AGWA; Miller et al. 2007; http://www.epa.gov/esd/land-sci/agwa/index.htm *and* http://www.tucson.ars.ag.gov/agwa), the DST used in this project, will assist the EPA and other agencies with permitting and enforcement responsibilities under Clean Water Act (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). 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). Qualitative or relative comparisons are presented without the calibration of baseline data. Results presented in the form of relative change can be interpreted by decision makers 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.

Methods

The methodology developed to ascertain local vulnerabilities and qualitative cumulative impacts associated with basin-wide development is a multi-step process. Project/watershed extent must first be defined in order to obtain data that covers the entire study area. Various land cover data must be converted to the appropriate format, compatible with AGWA, and soil inputs must be acquired. Daily precipitation records need to be located and formatted for the watershed, and daily weather generator stations for temperature, humidity, wind, and solar radiation data must be defined. Reservoirs need to be located, selected and setup for the Soil and Water Assessment Tool (SWAT; Neitsch et al. 2002; Srinivasan and Arnold 1994). Finally, AGWA is used to parameterize SWAT, the reservoirs are added to SWAT, and SWAT is executed for the baseline condition (2010) and future land cover/use scenarios (2020-2100).

Project/Watershed Extent

The first step of the methodology is defining an accurate project and watershed extent. The extent is used to locate other required data including land cover, soils, precipitation, climate and reservoir features. To define the project extent, the watershed is delineated in AGWA and given a buffer distance of five kilometers to ensure there are no gaps in coverage for the land cover and soils data. The watershed was delineated using a 30-meter digital elevation model (DEM) that had been hydrologically corrected to ensure proper surface water drainage (Appendix B – Figure 20). Modification of the DEM in this region, which involved “burning” in streams (Saunders 1999), was necessary to enforce proper drainage at the reservoirs due to the complicated network of diversions and canals that flow into and out of reservoirs. In the United States, 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 one recommended source for DEM data.

Land Cover

The land cover data used in this report comes from two sources. The National Land Cover Database 2006 (NLCD; Fry et al. 2011), available nationally, is used as the base land cover for the South Platte River Basin. The NLCD 2006 was used for the base land cover because it was the most current dataset for the United States at the time of modeling and because NLCD (from 2001 instead of 2006) has been used previously with ICLUS data to project future growth (Johnson et al. 2012). At the time of writing, the Multi-Resolution Land Characteristics Consortium (MRLC) has released a newer NLCD product, NLCD 2011 (Jin 2013). The ICLUS 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 emission storylines (Bierwagen et al. 2010; EPA 2009; EPA 2010; Table 1, Figure 2).

Table 1: Summary of the types of changes of the different ICLUS scenarios (EPA 2009).

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

The ICLUS HD data was combined with the NLCD 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 2).

Table 2: Explanation of ICLUS housing density categories (EPA 2010).

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 five seamless, national-scale change scenarios for urban and residential development (Table 1). The 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 United States (EPA 2009; EPA 2010). The final datasets provide decadal projections of both housing density and impervious surface cover from the 2010 baseline year projected out to the year 2100. The A2 Scenario is characterized by high fertility, high domestic migration and low net international migration; it represents the highest population gain of 690 million people in the United States by 2100 (Figure 2). The Base Case (BC) and the B2 Scenario are the middle scenarios, with medium fertility and medium to low domestic and international migration. An intermediate output of the ICLUS project provides population data by county for the conterminous United States projected by decade from the baseline (2010) to 2100; these population values were used to drive housing density growth (ORD 2007; EPA 2009). This dataset was also used to estimate population growth for the entire conterminous United States (Figure 2). For the South Platte River Basin, counties that intersected the basin were extracted and their projected populations were summed by decade in order to get an estimate of population growth for each scenario (Figure 3 and Appendix C – Figure 21).

Aside from population growth, differences in the way housing is allocated reflect a division in scenarios; sprawling development is inherent in scenarios A1, A2, and BC while compact growth patterns are reflected in scenarios B1 and B2. As a result of this distinction, the county populations in urban and suburban areas generally grow faster than in rural areas in the BC, 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 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).

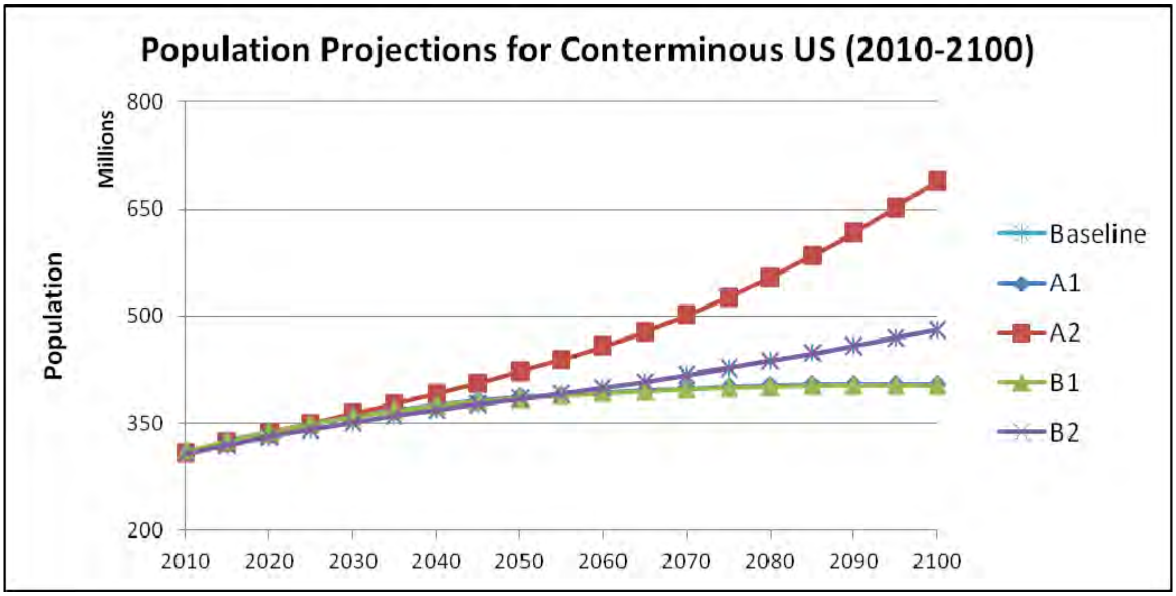

Figure 2: Population projections for ICLUS scenarios by decade (EPA 2009).

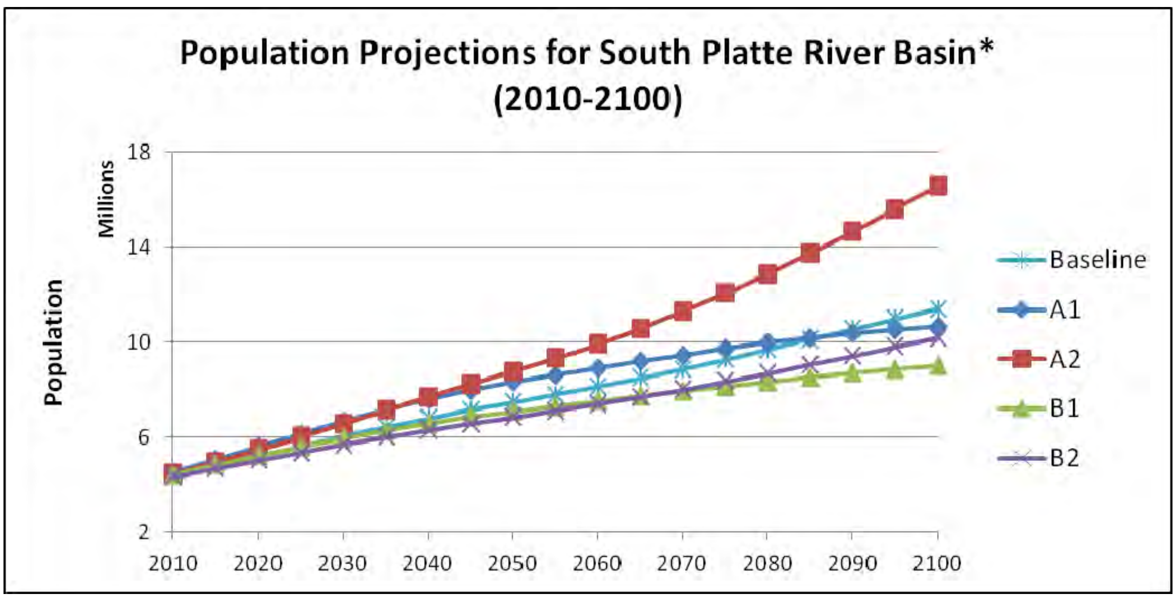

Figure 3: Population projections for ICLUS scenarios by decade for counties that intersect the South Platte River Basin (ORD 2007; Appendix B - Figure 21).

The NLCD data has different land cover classes, a different projection, and is at a different resolution (30 meters) than the ICLUS data (100 meters); therefore, the ICLUS data were pre-processed for use in this project. Preprocessing includes clipping the ICLUS data to the extent of the buffered South Platte River Basin, projecting the ICLUS data to UTM Zone 13 NAD 83, reclassifying the ICLUS data to NLCD classes (Table 3), and resampling the ICLUS data from 100 m to 30 m using the nearest neighbor assignment. The resulting dataset was then merged with the NLCD dataset so that ICLUS data replaced the NLCD data if there was a change in ICLUS housing density. 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 existing NLCD class over the extent. This methodology was incorporated into a tool in ArcToolbox in ESRI ArcMap for easy conversion of the ICLUS datasets (Appendix A, Figure 19).

Table 3: 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

Ten land cover datasets per scenario (50 total) were produced from the combination of the NLCD datasets and the ICLUS datasets, representing the change in landscape attributed to population and development changes per decade from 2010 to 2100 (Guy et al. 2011; EPA/600/C-12/0001). Table 8 through Table 12 in Appendix D contains the changes in land cover/use by decade for each of the ICLUS national scenarios. For each scenario, the converted ICLUS dataset from 2010 was used as the project baseline to which the successive decadal datasets were compared.

Soils

Soils data for the South Platte River Basin were obtained from the Natural Resources Conservation Service (NRCS) – Web Soil Survey. The Digital General Soil Map of the United States, or STATSGO, was downloaded for Wyoming, Nebraska and Colorado and subsequently merged to create a continuous soil layer that covered the entire project extent. The mapping scale of STATSGO is 1:250,000 (USDA-NRCS 1994).

Precipitation

Precipitation data was obtained from "Global Weather Data for SWAT" (http://globalweather.tamu.edu/; Globalweather 2014). This site utilizes the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) data for a 32-year period from January 1, 1979 through December 31, 2010 (Saha et al. 2010; Fuka et al. 2013). This source was used since it is easily available and downloadable in the required SWAT format. CFSR data includes daily precipitation amounts and was downloaded from stations within the project extent. CFSR interpolated point locations are given in geographic coordinates and are inserted into a feature class within ArcMap for use in AGWA. Precipitation data from 1979-2010 was reformatted for implementation in AGWA and missing dates were populated with "-99"; SWAT uses a built-in stochastic weather generator to determine how much precipitation to supply for the missing records. A total of 63 weather stations were used to generate precipitation and seven weather generating stations (WGN) were used to determine temperature inputs across the South Platte River Basin (Figure 1; Appendix B - Figure 20). Precipitation and temperature remain constant throughout the simulations.

Reservoirs

Reservoir information is maintained by multiple local, state, and federal entities. A large portion of this information can be found at the Colorado Decision Support Systems (CDSS) webpage under the heading of "Structures (Diversions)" at http://cdss.state.co.us/onlineTools/Pages/StructuresDiversions.aspx (CDSS 2014). The CDSS maintains records about structures as well as Geographic Information System (GIS) data by region. Within the South Platte River Basin in Colorado, the CDSS GIS layer documents 3,451 reservoirs of all shapes and sizes. The CDSS GIS product provides a web link to documented structure records for each reservoir; the records include monthly reservoir releases which are required for SWAT modeling. The United States Geological Survey also maintains a dataset of "Large" reservoirs for the entire United States. This dataset describes reservoirs that were completed prior to the start of 1988 with a normal capacity of at least 5,000 acre-feet or a maximum capacity of at least 25,000 acre-feet (Ruddy and Hitt 1990); normal capacity is defined by Ruddy and Hitt as the "total storage space, in acre-feet, below the normal retention level" (1990). The GIS layer produced from this dataset contains surface area and volume measurements for most large reservoirs across the nation.

Both the CDSS and USGS records were used to incorporate reservoir processes into the AGWA-SWAT modeling. Both layers were clipped to the extent of the South Platte River Basin. The clipped USGS reservoir locations were visually confirmed in ArcMap using a basemap and then clipped to a 500 meter buffer of the basins stream features in order to remove off-stream reservoirs from the analysis. Ten USGS records remained and the reservoir identifications were then compared with the 3,451 CDSS features to check for release records. In this case, four reservoirs were dropped from the analysis because they did not have the required monthly release information or were only cataloged in either the CDSS dataset or the USGS dataset. Without the necessary inputs for SWAT, we were unable to include these four reservoirs in the modeling. The final point layer contained six reservoirs which were to be modeled in SWAT (Figure 1; Table 4).

Table 4: Reservoirs Included in the SWAT Modeling of the South Platte River Basin.

Reservoirs		
Number	Name	Normal Capacity (10^4 m^3)
150	Spinney Mountain	6722
35	Eleven Mile	12063
19	Cheesman	9752
151	Strontia Springs	950
20	Cherry Creek	1722
85	Milton Seaman	618

SWAT requires surface area and volume of the reservoir at the principle spillway and at the emergency spillway; measurements were found in the USGS data for volume in acre-feet, which was converted to cubic meters, and for surface area, which was given in acres and converted to hectare. For example, normal capacity given in the USGS dataset was used as an input for volume at the principle spillway. SWAT also utilizes minimum and maximum average daily release information summarized by month as well as average daily release values, by month, in cubic meters per second which were given and/or calculated from the CDSS records. ArcMap was used to relate reservoirs with stream reach and subwatershed. Those relationships were used to manually alter the SWAT input files that were written by AGWA. SWAT was then executed outside of AGWA and the results were imported into the GIS environment for visualization.

AGWA-SWAT Modeling

The AGWA tool was used to model the South Platte River Basin with SWAT. 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; Goodrich et al. 2012) and SWAT (Arnold et al. 1994; Tuppad et al. 2011), within a GIS. In addition to the coupling of hydrologic models and GIS, the AGWA tool performs watershed delineation and characterization, 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.

SWAT can also model the movement of water and sediment through a reservoir based on user defined inputs which will alter volume of water and sediment flowing through modeled channel networks. SWAT uses surface area, volume and average daily outflow summarized by month to calculate volume of outflow and changes in reservoir volume over the simulation period. For controlled reservoirs, the model is based on static outflow rates that represent historic averages measured at each of the six reservoirs included in the simulation; the model also uses weather inputs based on the subwatershed that the reservoir resides in; temperature and precipitation information is also constant throughout the simulations. SWAT was used to model the relative impact of water and sediment trapping in large reservoirs within the South Platte River Basin. However, in order to comprehensively assess water quality and quantity impacts at lakes and reservoirs, other hydrologic models with reservoir water quality components would be required (Narasimhan et al. 2009).

The South Platte River Basin was subdivided into 61 subwatersheds and 42 channels. Subdivided watersheds were characterized using a 30 meter DEM and derived flow direction and flow accumulation grids, STATSGO soils, 66 precipitation stations, seven WGN stations, and the 50 land cover datasets (produced by combining ICLUS and NLCD datasets at decadal intervals) to produce 50 different simulations. SWAT was executed outside of AGWA so the six large reservoirs within the basin could be incorporated into the model, but model results were visualized within AGWA. 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 of land 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". HUI was calculated for each scenario and decade with absolute differences, in percent, representing the change in HUI from the base year 2010. The ICLUS A2 scenario resulted in the largest increase of the HUI, 1.8% in year 2100 for the entire watershed (Figure 4 and Appendix C - Table 5). Land cover conversion to developed classes from low to high intensity slowed in the second half of the century across the whole watershed; under scenario A2 peak growth of “Developed, Low Intensity” happened in 2050 at 12.8%, followed by a peak of “Developed, Medium Intensity” in 2060 at 69.0%, and finally “Developed, High Intensity” in 2100 at 160.2% (Appendix D - Table 9).

Similar 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, 2.7% (see Figure 5, Figure 6, and Appendix C - Table 6 and Table 7). Percent change, for every metric excluding HUI, was calculated using the following equation:

$$\frac{([decade_i] - [base_i])}{[base_i]} x100$$

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.

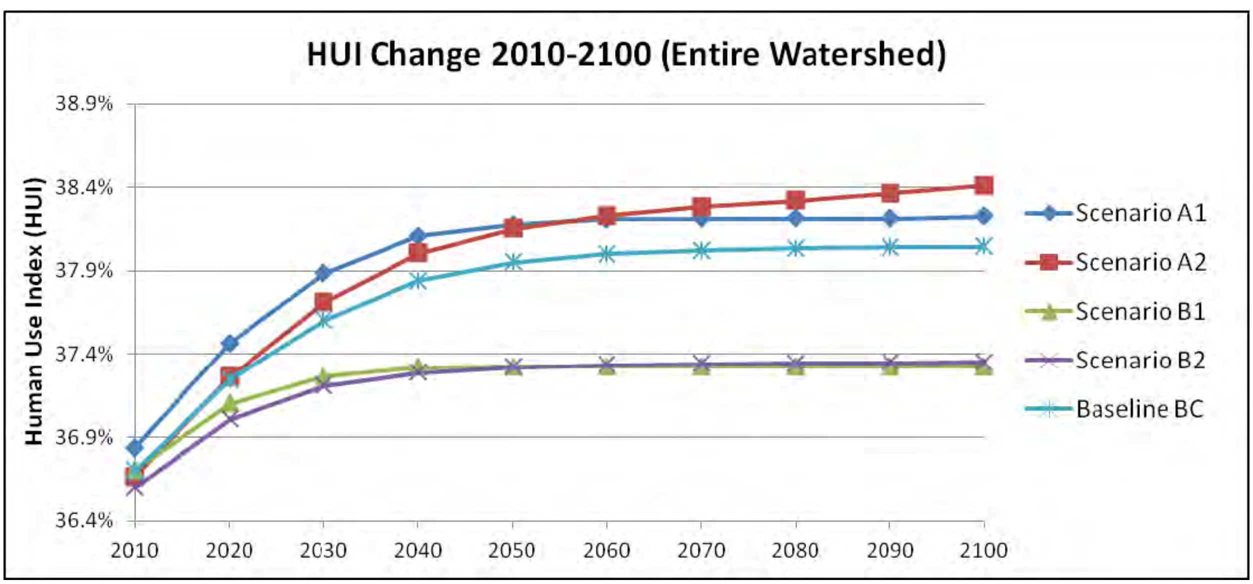

Figure 4: Watershed Human Use Index (HUI) for all scenarios.

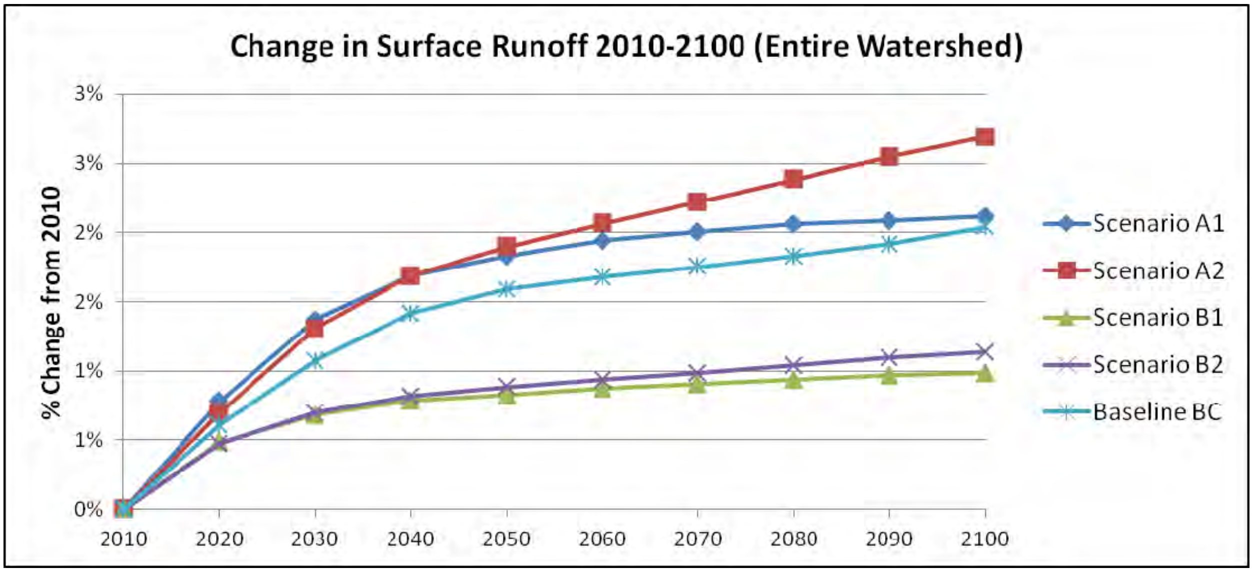

Figure 5: **Watershed average percent change in average annual surface runoff for all scenarios.**

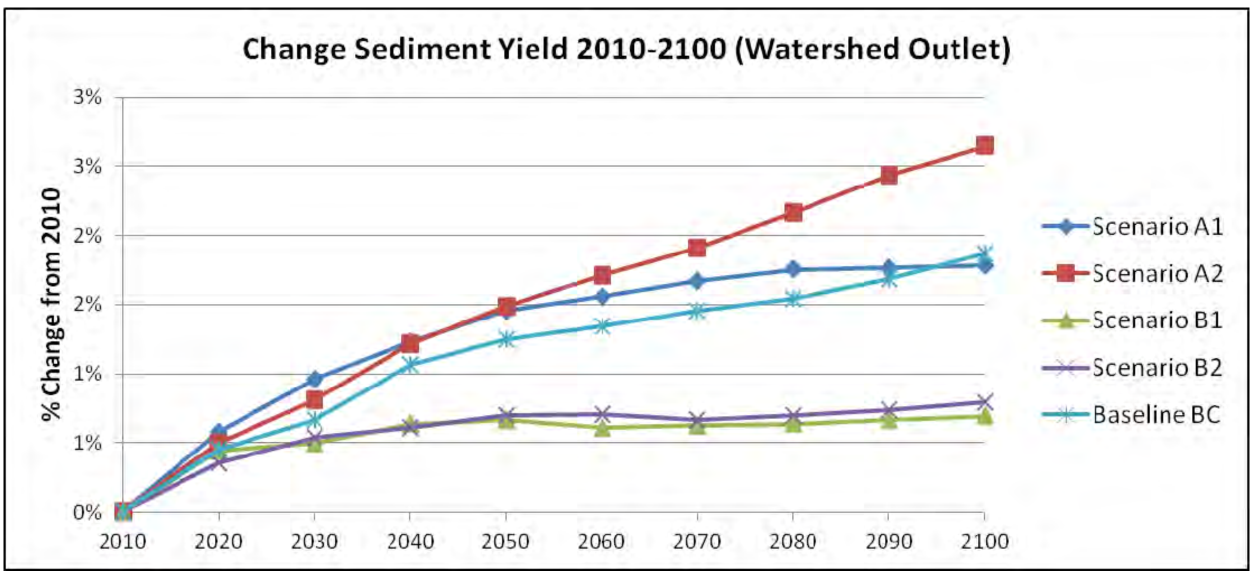

Figure 6: **Watershed average percent change in average annual sediment yield for all scenarios.**

In contrast to the relatively low percent change at the whole watershed scale, notably larger changes were seen in some subwatersheds. In scenario A2, the scenario with the most population growth, one subwatershed (#340; Appendix C - Figure 22), resulted in a much larger increase of up to 9.5 % in the HUI in year 2100 (subwatershed #340; Figure 7 and Appendix C- Table 5). This subwatershed saw increases in surface runoff and sediment yield of 17.6% and 15.1% respectively, corresponding to the increased HUI (Figure 8, Figure 9, and Appendix C – Table 6 and Table 7). This contrast is indicative of the spatial variability of growth within the South Platte River Basin, where projected growth is concentrated in the higher elevations near Denver, CO.

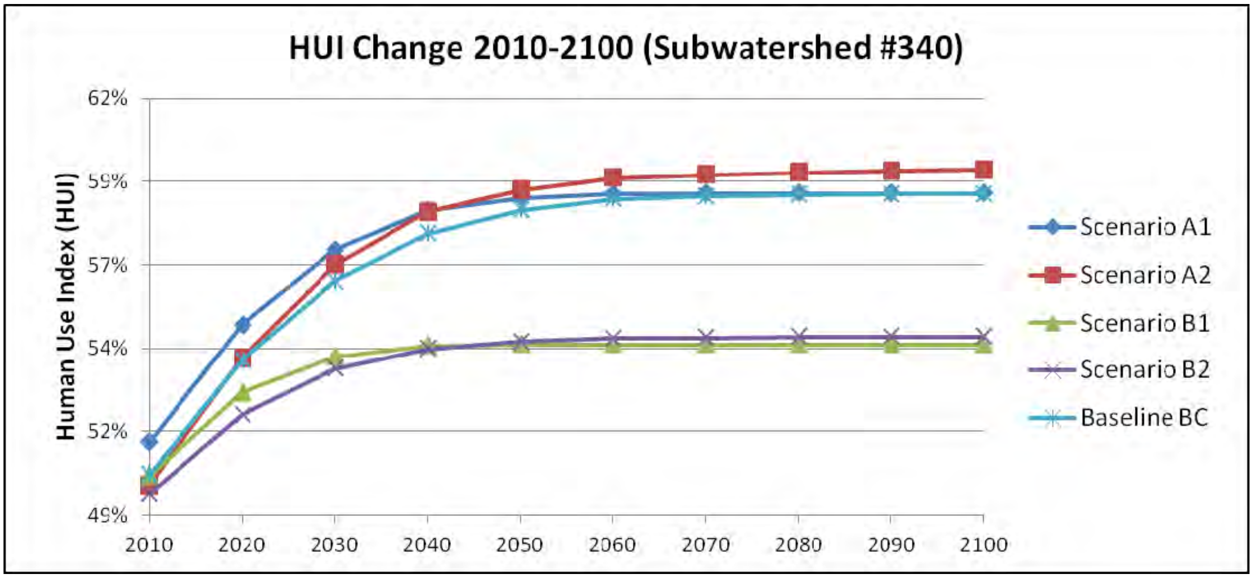

Figure 7: Subwatershed #340 Human Use Index (HUI) for all scenarios.

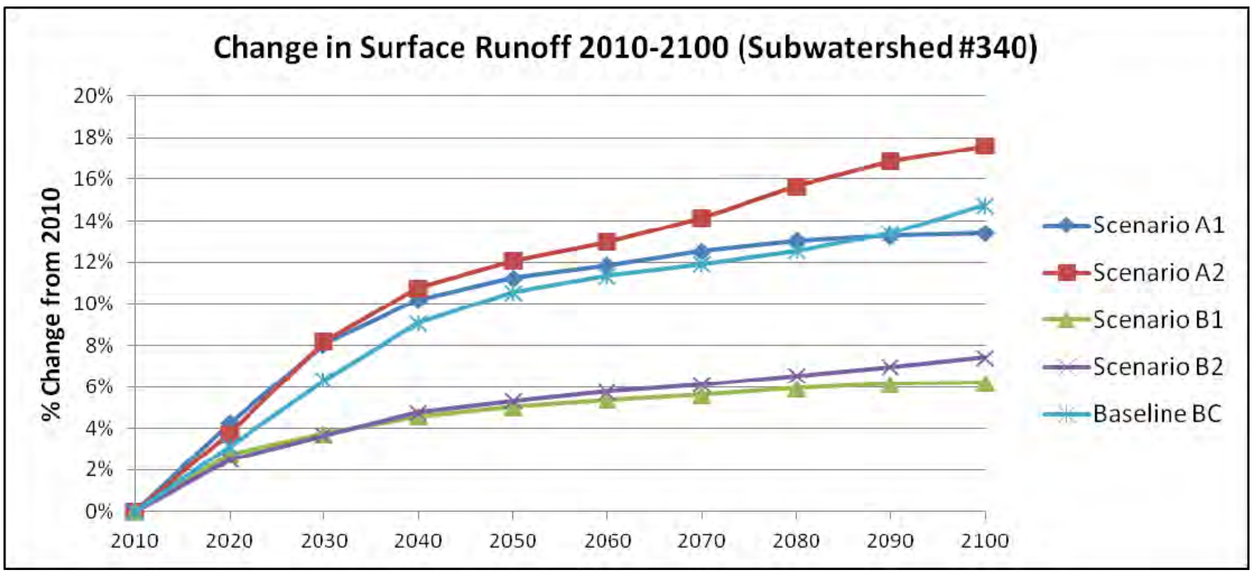

Figure 8: Subwatershed #340 average percent change in average annual surface runoff for all scenarios.

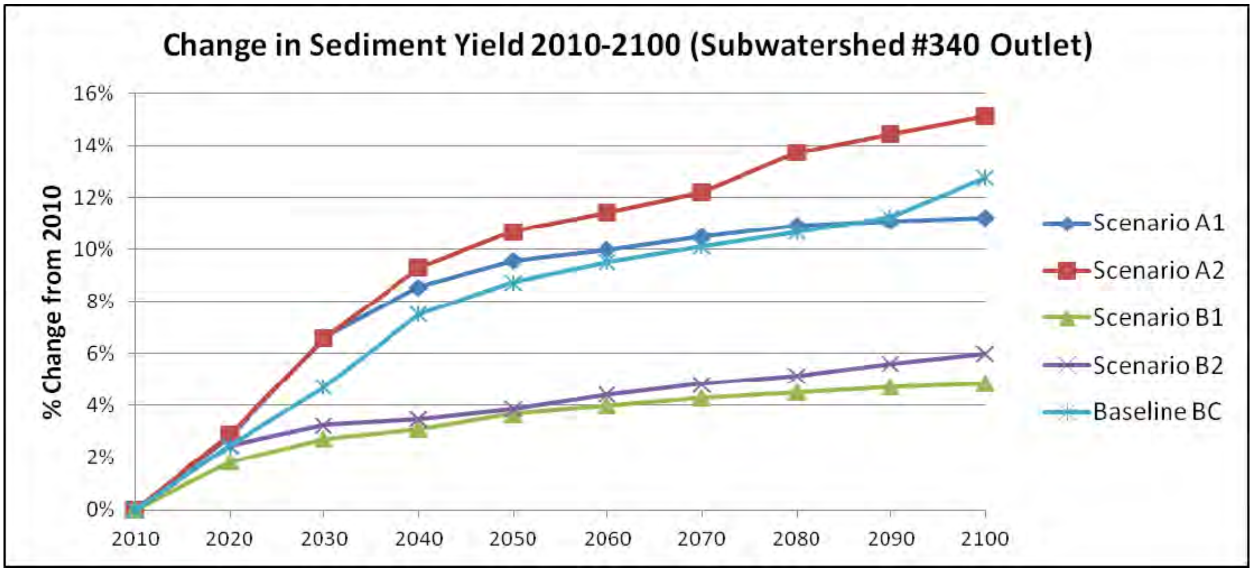

Figure 9: Subwatershed #340 average percent change in average annual sediment yield for all scenarios.

The spatial distribution of land cover change in 2100 under scenario B1 and A2 can be seen across the watershed in Figure 10, where anthropogenic land use includes areas that were used to calculate the HUI and "undeveloped" areas are those that are left unaffected by humans through 2100. In scenario A2, 63.3% of the watershed is unaffected by humans in 2010, this area decreases to 61.6% in 2100 because of housing development. Figure 10 divides HUI or anthropogenic land use into two categories that exhibit distinct hydrologic function. "Anthropogenic Land Use – Developed" represents NLCD classes "Developed, Open Space"; "Developed, Low Intensity"; "Developed, Medium Intensity"; "Developed, High Intensity". Whereas "Anthropogenic Land Use – Agriculture" includes NLCD classes "Pasture/Hay"; and "Cultivated Crops". Noticeably less land cover change is projected to occur between 2010 and 2100 in the Great Plains region where "Anthropogenic Land Use – Agriculture" is dominant; HUI change is minimal in those areas and can be seen in Figure 14 through Figure 18 along with associated changes in water and sediment yield.

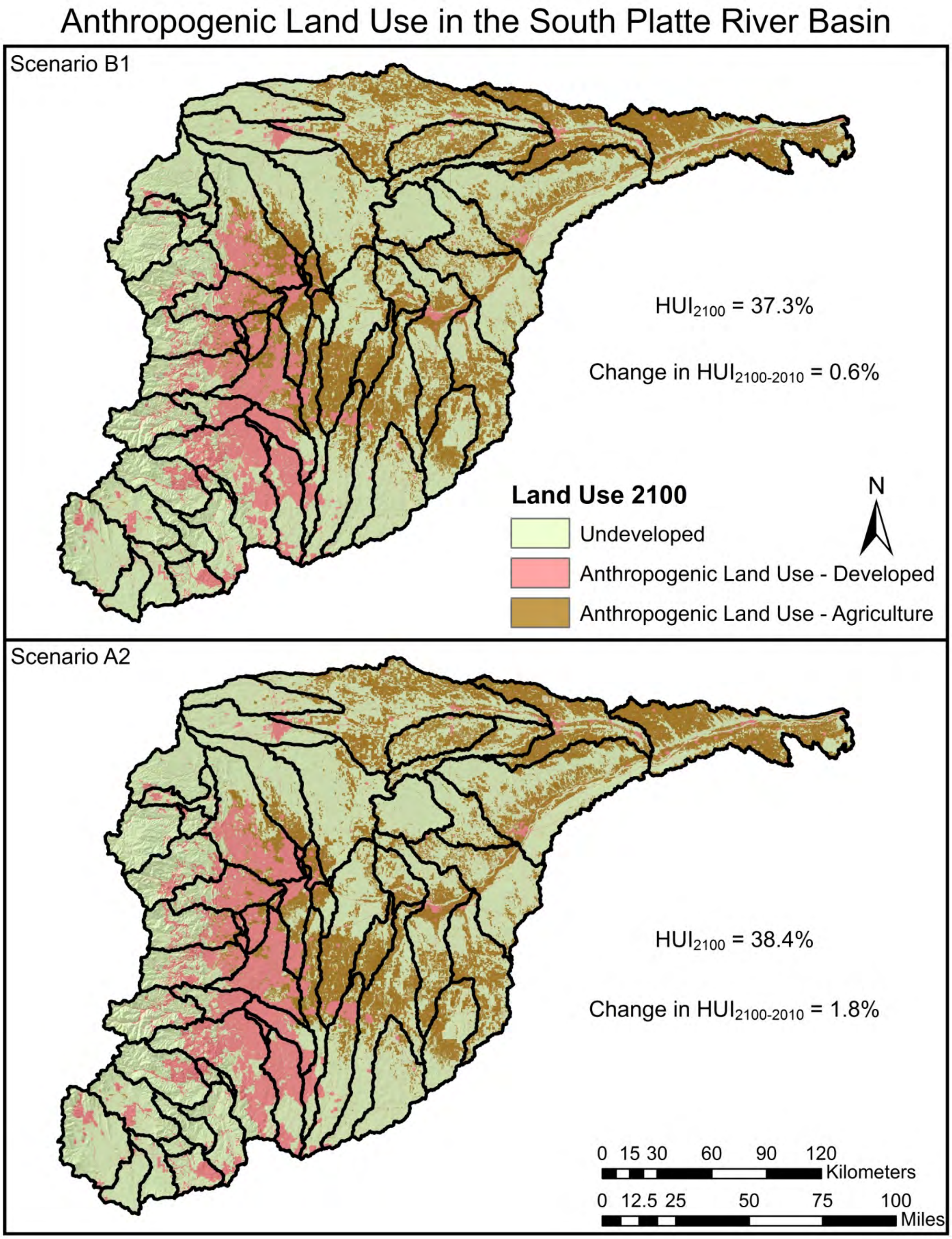

Figure 10: Spatial distribution of anthropogenic land use in the year 2100 under scenarios B1 and A2.

In order to understand the effect of reservoirs on water and sediment yield, scenario A2 year 2010 was executed with and without the six reservoirs. The results of SWAT reservoir modeling indicated an impact on the amount of sediment and water yield through streams in the South Platte River Basin (Figure 11 and Figure 12). Reservoirs appear to have a more pronounced impact on the stream reach and subwatershed scale where reductions in sediment and streamflow were 93.3% and 78.7%, respectively; impacts of reservoirs were still seen at the watershed outlet where reduction in sediment yield was 52.9% and streamflow was reduced by 39.0% (Figure 11 and Figure 12). Changes in land cover from 2010 to 2100 are projected to impact reservoir sedimentation and thus storage which can be seen in Figure 13. The bar graph in Figure 13 shows that in 2010 under scenario A2, SWAT predicts only 15.8% of the sediment yield above Strontia Springs Reservoir will remain at the outlet of subwatershed #340, downstream of the reservoir. In 2100, SWAT modeling predicted 18.0% of sediment entering the reservoir will remain in the channel at the outlet of subwatershed #340. This indicates storage of water and sedimentation in the reservoir. Since historic reservoir water quality was not used for these simulations, sediment yield above and below Strontia Springs Reservoir is presented as a percentage of sediment flowing into the reservoir; absolute values reported are to emphasize reservoir function. The six reservoirs modeled in SWAT for this report had an impact on sediment yield and water yield within the South Platte River Basin.

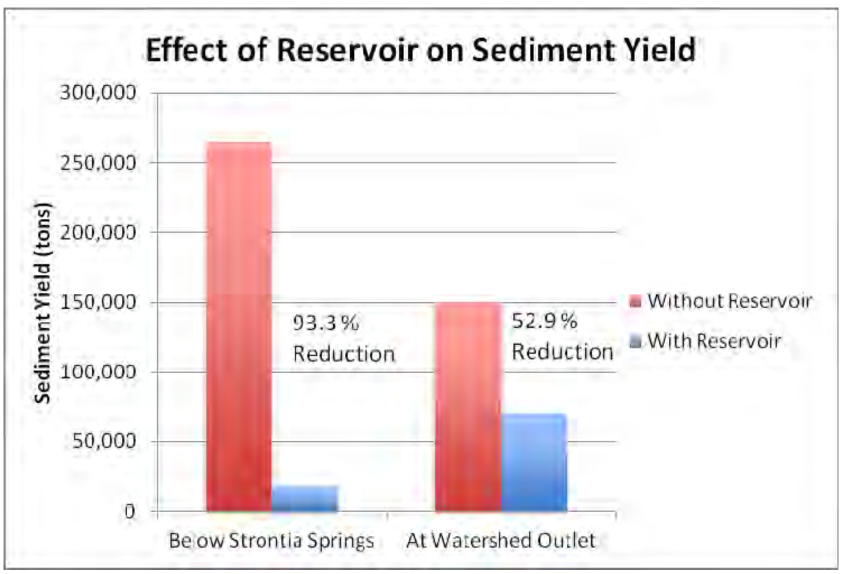

Figure 11: Effect of reservoirs modeled in SWAT on sediment yield at the watershed outlet and below Strontia Springs Reservoir.

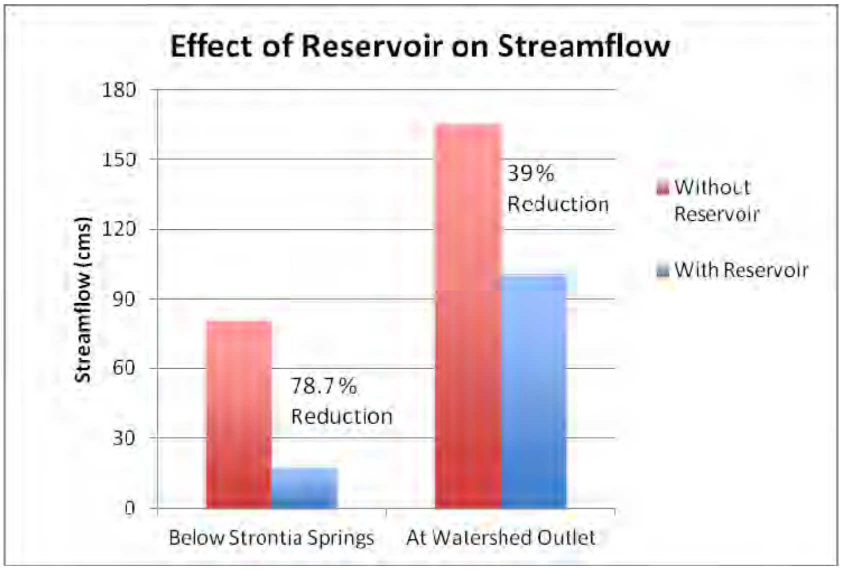

Figure 12: Effect of reservoirs modeled in SWAT on streamflow below Strontia Springs Reservoir and at the watershed outlet.

Figure 14 through Figure 18 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 within the subwatersheds and contrast that variability with averaging the impacts over the entire watershed as presented in Table 6 and Table 7. Table 8 through Table 12 in Appendix D present absolute and relative changes in land cover/use across the entire South Platte River Basin.

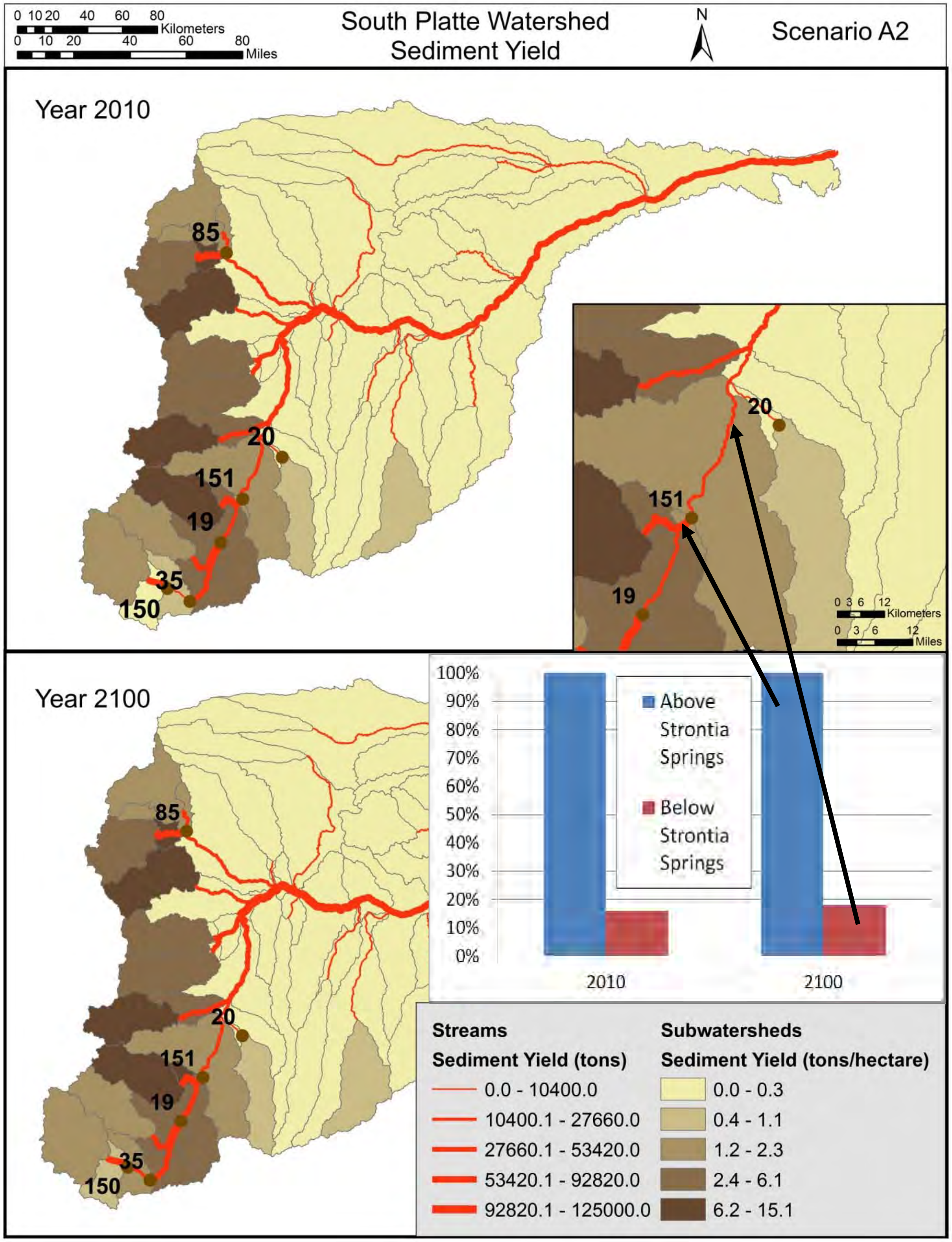

Figure 13: **Sediment yield within the South Platte River Basin, emphasis on the Strontia Springs Reservoir (reservoir #151) where sediment yield decreases downstream of the impoundment. Bar graph illustrates the difference in sediment yield portrayed in the map as a percentage of sediment yield flowing above Strontia Springs.**

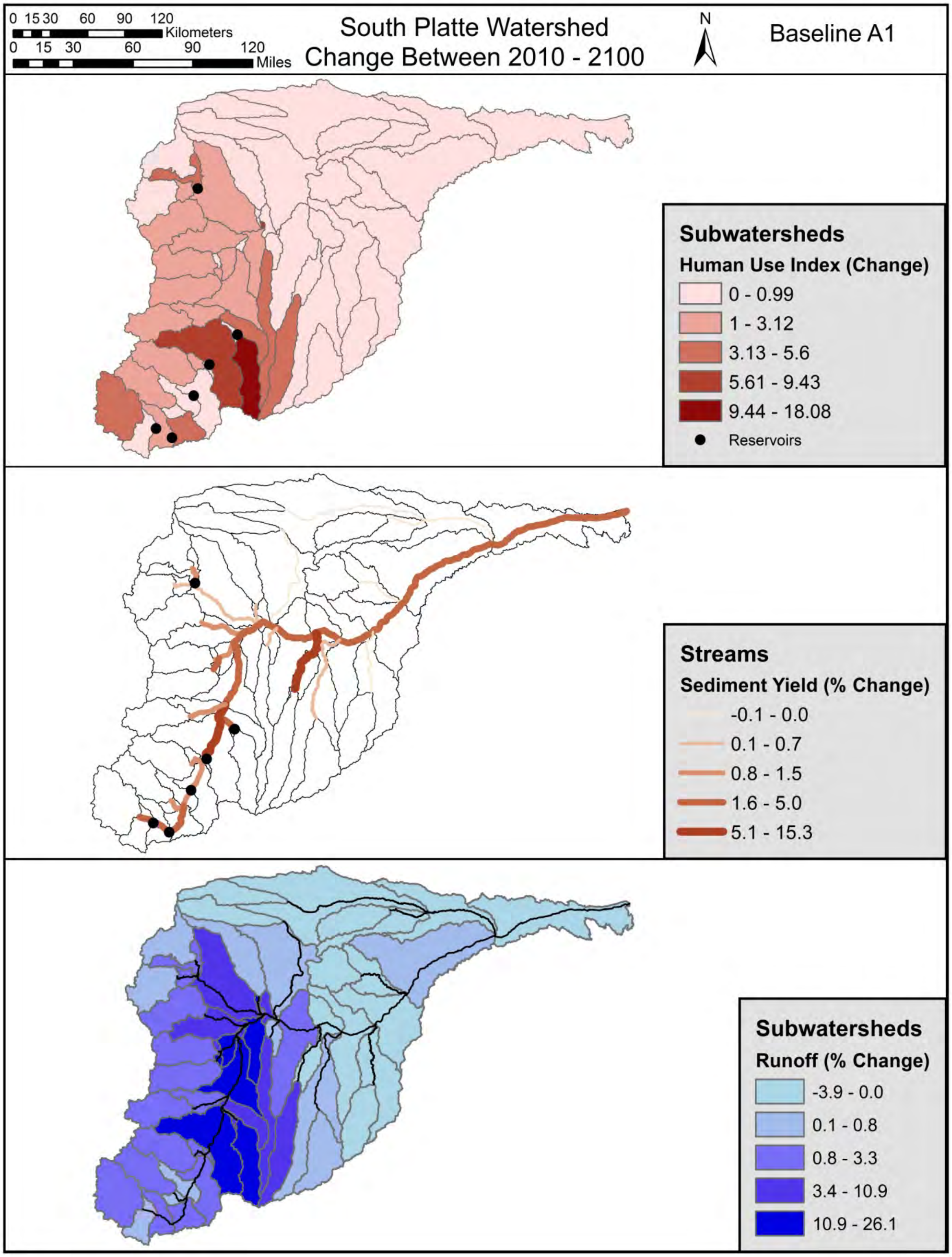

Figure 14: Change in Human Use Index (HUI), average annual sediment yield, and average annual surface runoff in percent from 2010 to 2100 for scenario A1.

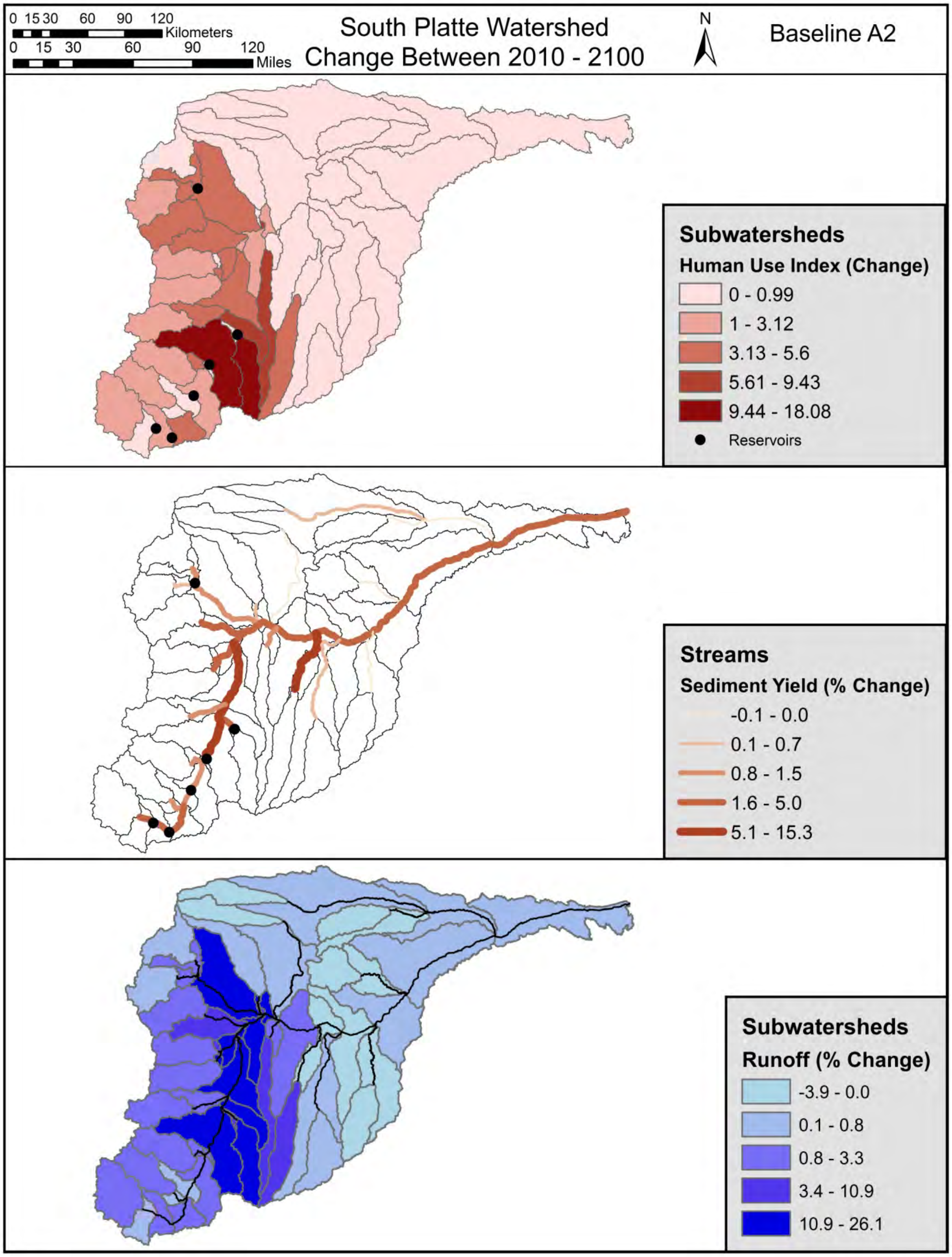

Figure 15: Change in Human Use Index (HUI), average annual sediment yield, and average annual surface runoff in percent from 2010 to 2100 for scenario A2.

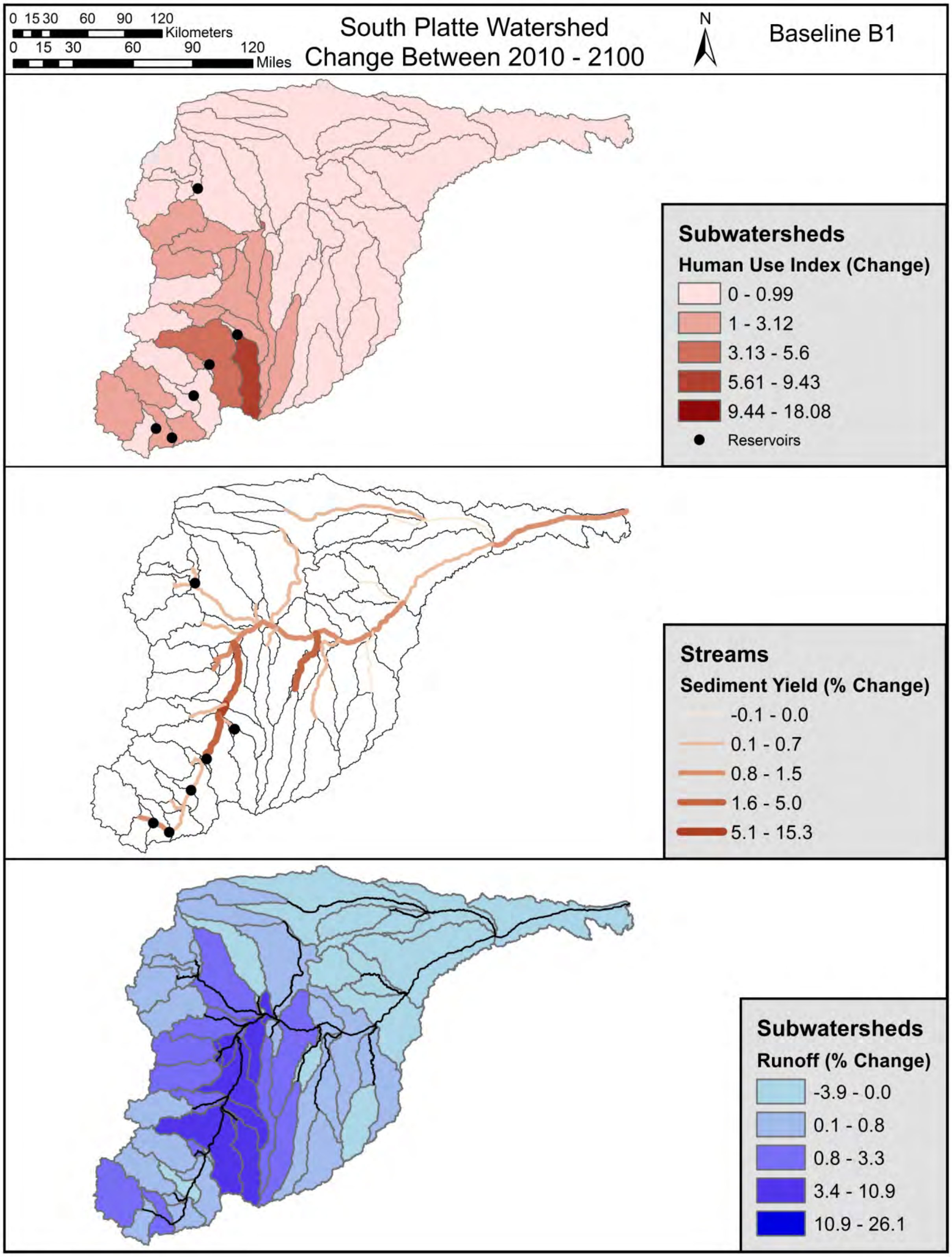

Figure 16: Change in Human Use Index (HUI), average annual sediment yield, and average annual surface runoff in percent from 2010 to 2100 for scenario B1.

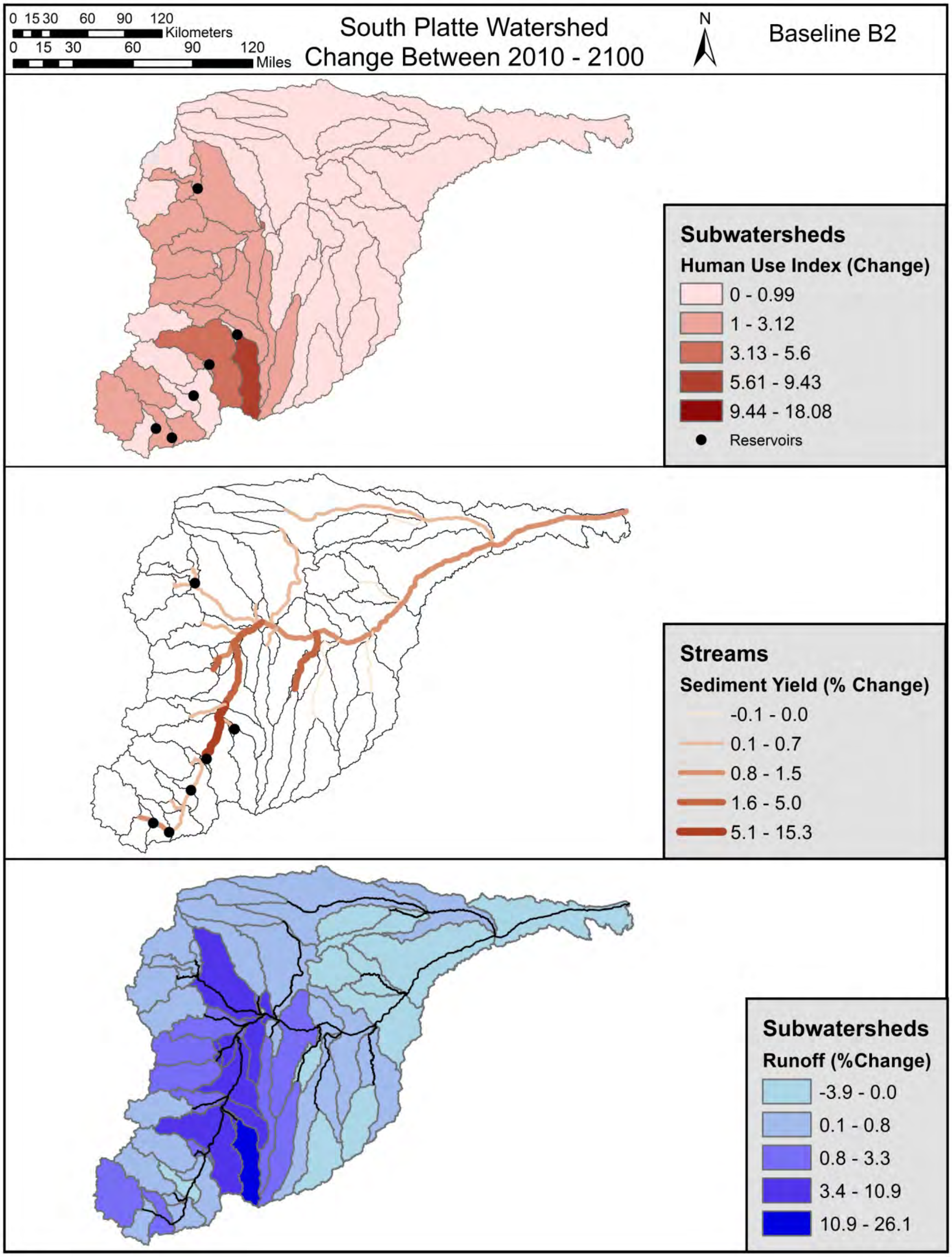

Figure 17: Change in Human Use Index (HUI), average annual sediment yield, and average annual surface runoff in percent from 2010 to 2100 for scenario B2.

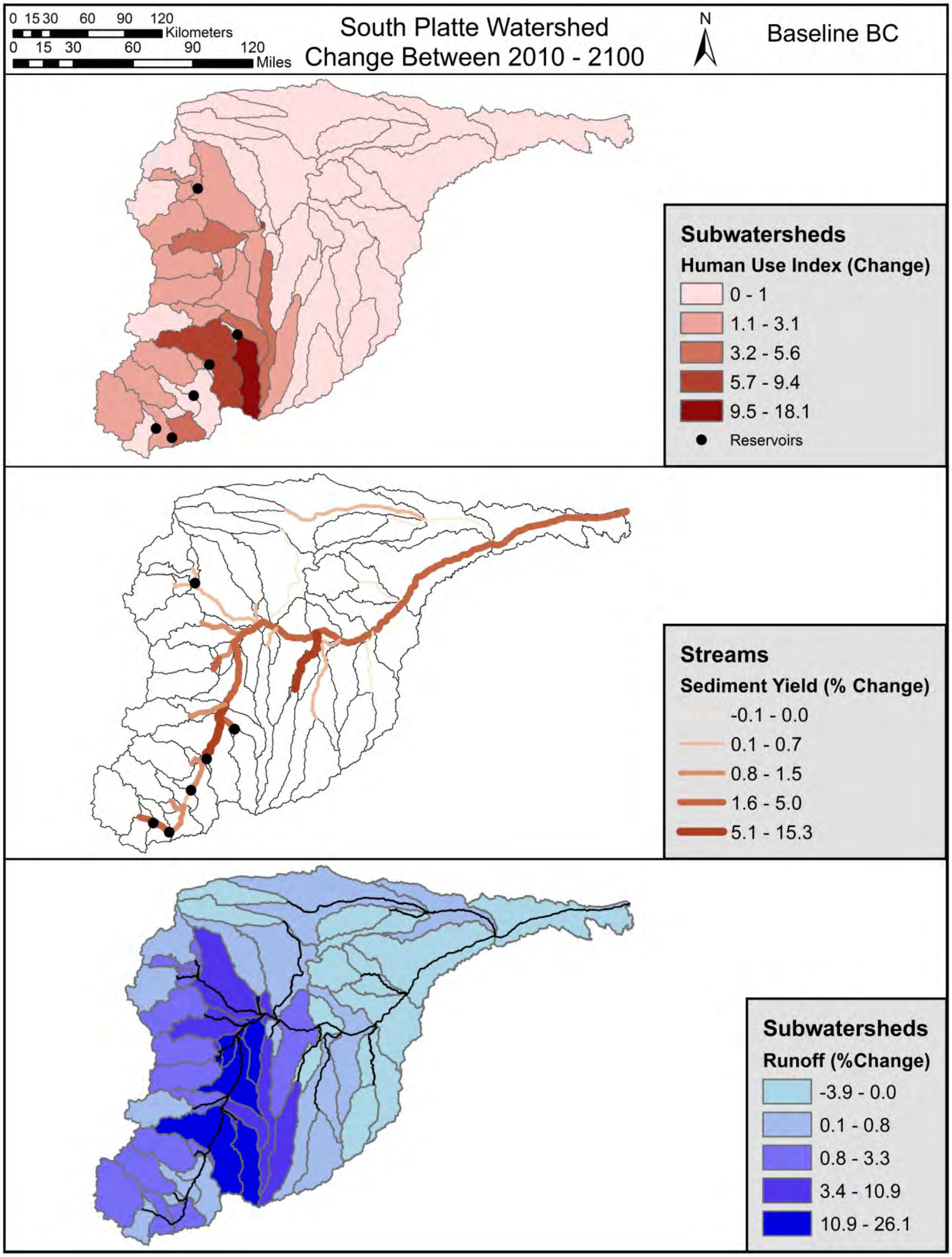

Figure 18: Change in Human Use Index (HUI), average annual sediment yield, and average annual surface runoff in percent from 2010 to 2100 for scenario BC.

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. CFSR rainfall and climate data are used to drive the SWAT model and held constant throughout the simulations so that conclusions can be drawn related to the impacts of predicted land cover change under the different ICLUS scenarios. Using static rainfall and climate data, the results of those simulations do not account for anticipated climate change, although climate change may amplify or abate the results presented here based on predicted changes to temperature and precipitation characteristics. Quantitative assessments of anticipated hydrologic impacts resulting from the ICLUS scenarios would require rainfall and climate observations, calibration of 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, constructed wetlands etc.) that would be a required component of any future development.

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 land cover change are not averaged out by the large metropolitan area supported by large cropland and pasture developments contained in the ~61,700 km^2 watershed. Under all five scenarios, in the baseline year 2010, at least one-third of the land area in the South Platte River Basin was classified under anthropogenic land use, which includes land developed for housing as well as land used for agricultural production. Under the most dramatic development scenario, A2, the HUI or percentage of anthropogenic land use only increased by 1.8% in 2100.

The methodology presented herein uses HUI as a 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. 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 hydrologic modeling, which more closely captures the actual land cover properties and the complex interactions and feedbacks that occur across a watershed.

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. It is apparent that changes driven by anthropogenic activities have an impact on hydrologic processes throughout the watershed.

Land use can contribute to the rate of sediment deposition and contaminant delivery in reservoirs and may impact their water-storage capacity and water quality, although this is not accounted for in this analysis (Mau and Christensen 2000). Sedimentation in reservoirs reduced the impact of sediment loads downstream and could mitigate water quality impairments in lower stream reaches. While wetland function was not modeled in this analysis, it is important to note that wetlands often control flooding, sediment yield and erosion. Land cover change predicted by ICLUS resulted in losses of wetland across the entire watershed by the year 2100 ranging from -2.9% under scenario B1 to -7.8% under scenario A2 (Appendix D - Table 8 through Table 12). The impact of reservoirs, wetlands and diversions is apparent when looking at the watershed average or outlet and will likely regulate future impacts downstream; however, this effect is more pronounced at the subwatershed and stream reach scale.

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 more significant than at the basin scale. Thus, any interests in cumulative effect of land use changes should be addressed at the subwatershed scale versus the basin scale for this large western watershed with significant public land holdings, or others like it which contain large tracts of land that will likely remain undeveloped, and are therefore not subject to direct urbanization impacts.

Also highlighted in the South Platte River Basin is the timing of development; the largest increases in HUI under every scenario took place by 2050 after which only minor increases in HUI occurred. Under scenario A2, by 2060 the entire watershed saw an increase in HUI of 1.6% compared to the percent increase of HUI from 2010 to 2100 of 1.8%. This is likely due to a shift which is observed among developed land cover classes; under every scenario there was a transition from “Developed, Low Intensity” towards “Developed, High Intensity” by 2100 (Appendix D – Table 8 through Table 12). Corresponding to the overall increase in HUI are large increases in sediment yield and surface runoff in the first five decades of analysis. Under these circumstances, it is important to look at impacts under different temporal scales to understand when management or mitigation measures will be most effective. The temporal and spatial scales at which watersheds are evaluated are important factors to understanding how land cover change will impact hydrologic ecosystem services.

Conclusions

The primary objective of this analysis was to evaluate the relative hydrologic impacts of future growth through time, which was accomplished 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 on hydrologic response at different spatial and temporal scales to help identify vulnerable regions and evaluate the impacts of management. Analyzing the hydrologic response of a watershed at multiple scales can highlight vulnerable stream reaches or subwatersheds due to the extent of land use and land cover change. AGWA also allows for assessment of basin-wide changes and cumulative effects at the watershed outlet.

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 resulted in the greatest predicted 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 (Table 6 and Table 7) indicate changes in the range of 1.0% (B1 scenario) to 2.7% (A2 scenario) in average annual surface runoff across the watershed, and changes in the range of 0.7% (B1 scenario) to 2.7% (A2 scenario) in 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 4.9% (B1 scenario) to 15.1% (A2 scenario) and the change in surface runoff ranges from 6.2% (B1 scenario) to 17.6% (A2 scenario).

Simulated increases in percent change of surface runoff and sediment yield closely tracked increases in the HUI metric likely due to the development of impervious surfaces associated with urbanization; consequently, growth and development should be moderated using green infrastructure, low impact development, or other best management practices (BMPs) 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, increase sedimentation in reservoirs, and increase flooding. The effects of growth may be magnified or mitigated by climate change or the implementation of BMPs, though this is not accounted for in this analysis (Pyke et al. 2011). However, simplified simulations that reflect cumulative potential impacts due to population growth and land cover/use change may be used to inform water resource or land managers in the permitting, planning and decision making context.

At present, issuance of ACOE CWA Section 404 individual permits are carried out in a project-by-project fashion without much information to support an analysis of the collective impacts of multiple projects on 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 the 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]).

The quality and quantity of U.S. waters has been gaining public recognition in the face of rapid development and climate change. Non-point source pollution contributing sediment or pollutants from urban, agricultural, or natural lands can lead to the impairment of water resources. Land cover/use change can often exacerbate water quality impairments and lead to changes in local hydrology. In the Front Range, mountainous streams that are more sensitive to water quality impacts could face increasing threat due to predicted land conversion and urban development (Caulfield et al. 1987).

Identification of sensitive or vulnerable streams and subwatersheds within a large watershed can be accomplished using AGWA. When used with current and accurate data, outputs from AGWA can provide important information for land and resource managers utilizing the scenario analysis approach. In order to best serve this purpose, it is important to use the most up to date model inputs; future research will incorporate the updated NLCD 2011 data and potentially new projections of land cover and land use change. A new framework in place of the SRES storylines is the representative concentration pathways (RCPs) (van Vuuren et al. 2011); should these be used to predict population and land cover change, the spatial data could also be used to assess the impacts of different RCPs on watershed hydrology. In addition to updating land cover inputs, future research could incorporate observed precipitation and temperature data along with predicted changes in temperature and precipitation to understand the relative impact of climate change in the South Platte River Basin. Utilizing a variety of scenarios can provide decision makers with a suite of possible changes related to runoff and sediment yield from which to develop new policy or management plans at different spatial and temporal scales.

Assessing possible impacts of land use, climate change, or management options across multiple scales will highlight different vulnerabilities across a watershed. Local changes to hydrology and sediment delivery at the subwatershed level are relevant because at those scales the impacts tend to be much more significant. Additionally, in a large watershed such as the South Platte, a single management option may not be viable from the forest to the plains. Management, reclamation and restoration of hydrologic processes for the benefit of water resources will be more effective at the subwatershed scale. Since hydrologic impacts are tied to changes in land cover, these impacts at a watershed scale are expected to be limited. Large watersheds will have complex hydrologic functions such as diversions, dams and reservoirs that will impact the hydrologic characteristics at the watershed scale. In order to best inform land and water resource managers about potential changes in watershed health and hydrology, a broad range of scenarios needs to be assessed across different scales.

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

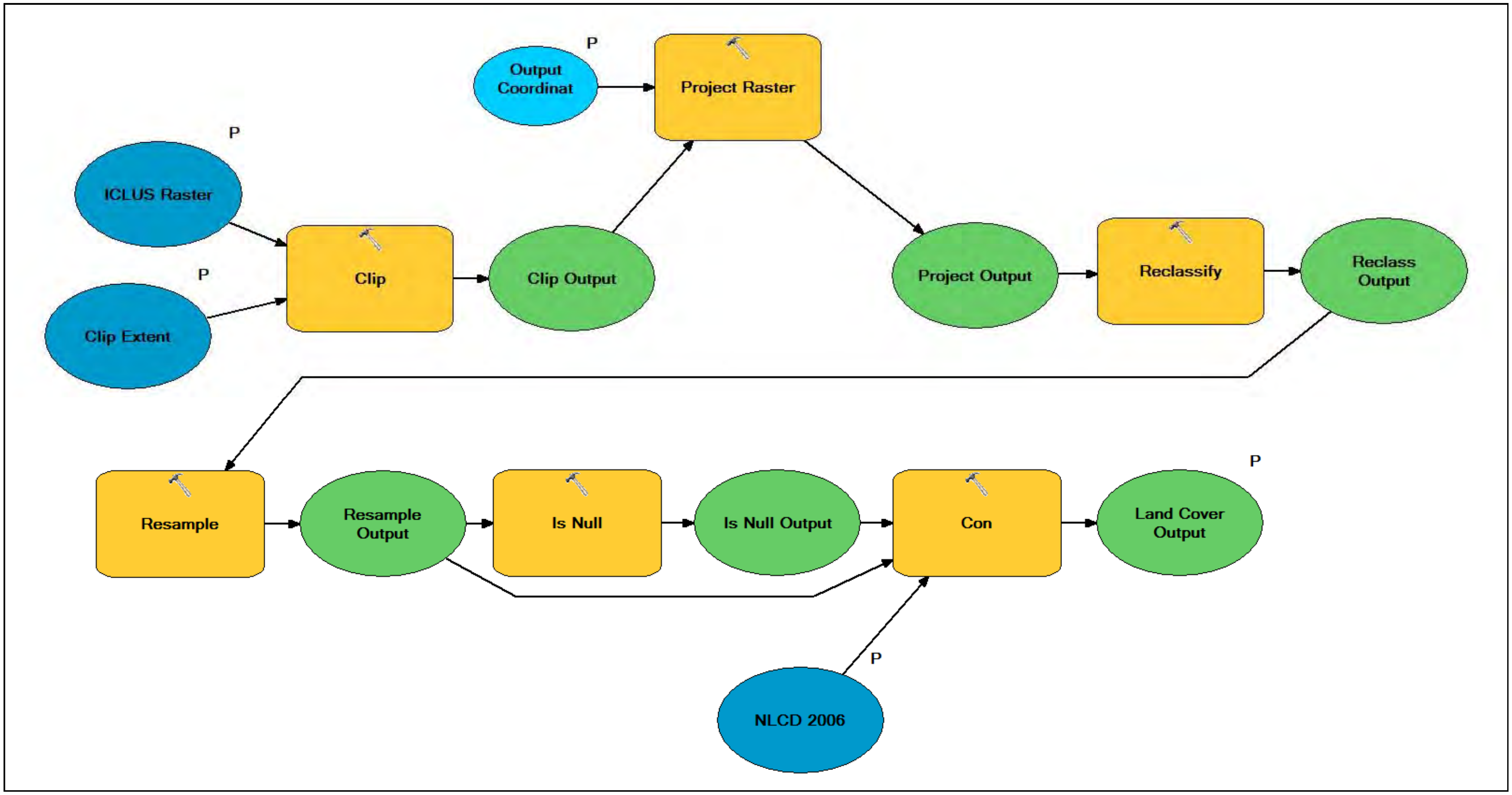

Figure 19: ArcMap Geoprocessing Model that Clipped, Projected, and Reclassified the ICLUS Data into Classified Land Cover for use in AGWA.

Appendix B

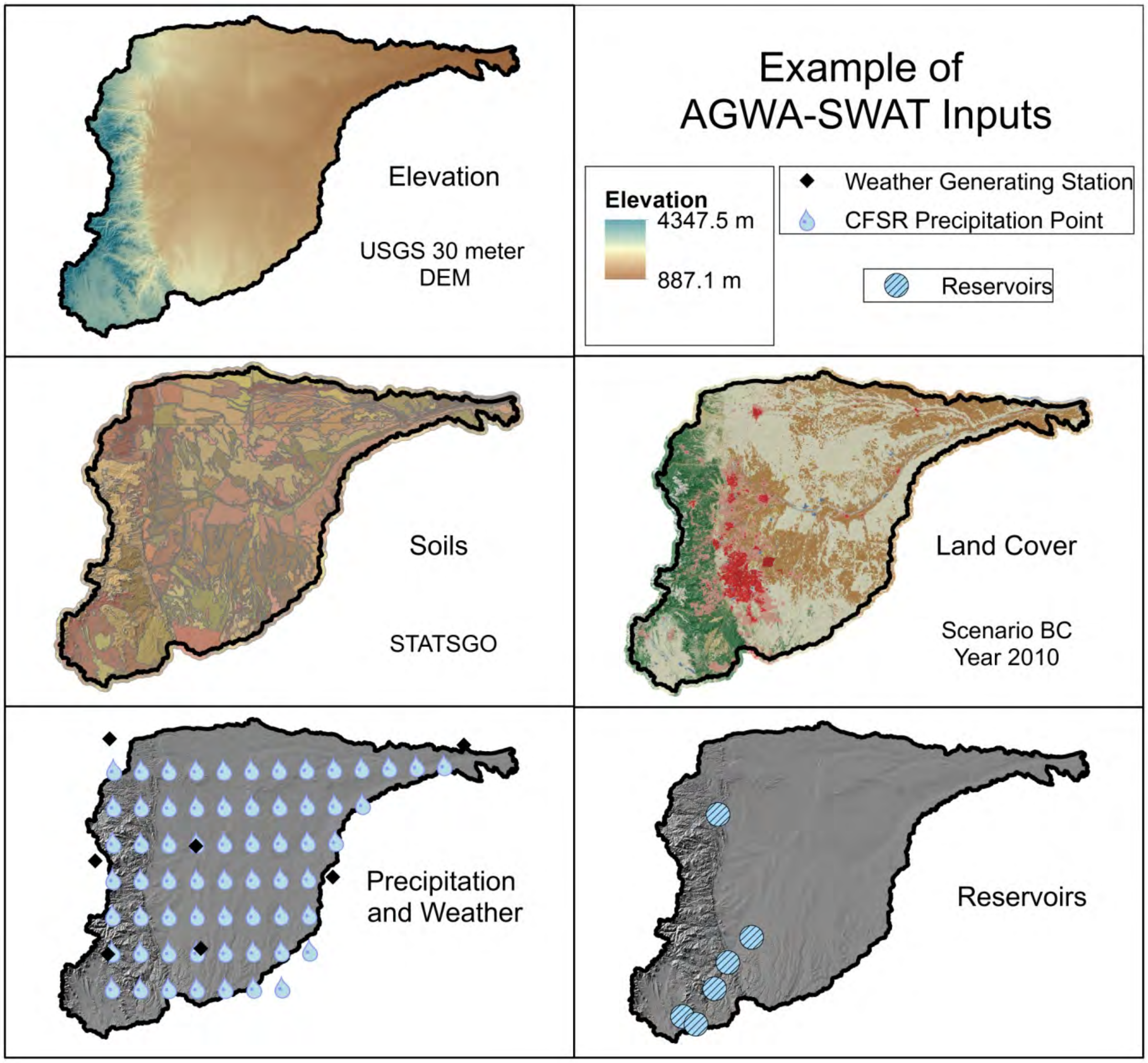

Figure 20: Example of inputs used to run AGWA-SWAT.

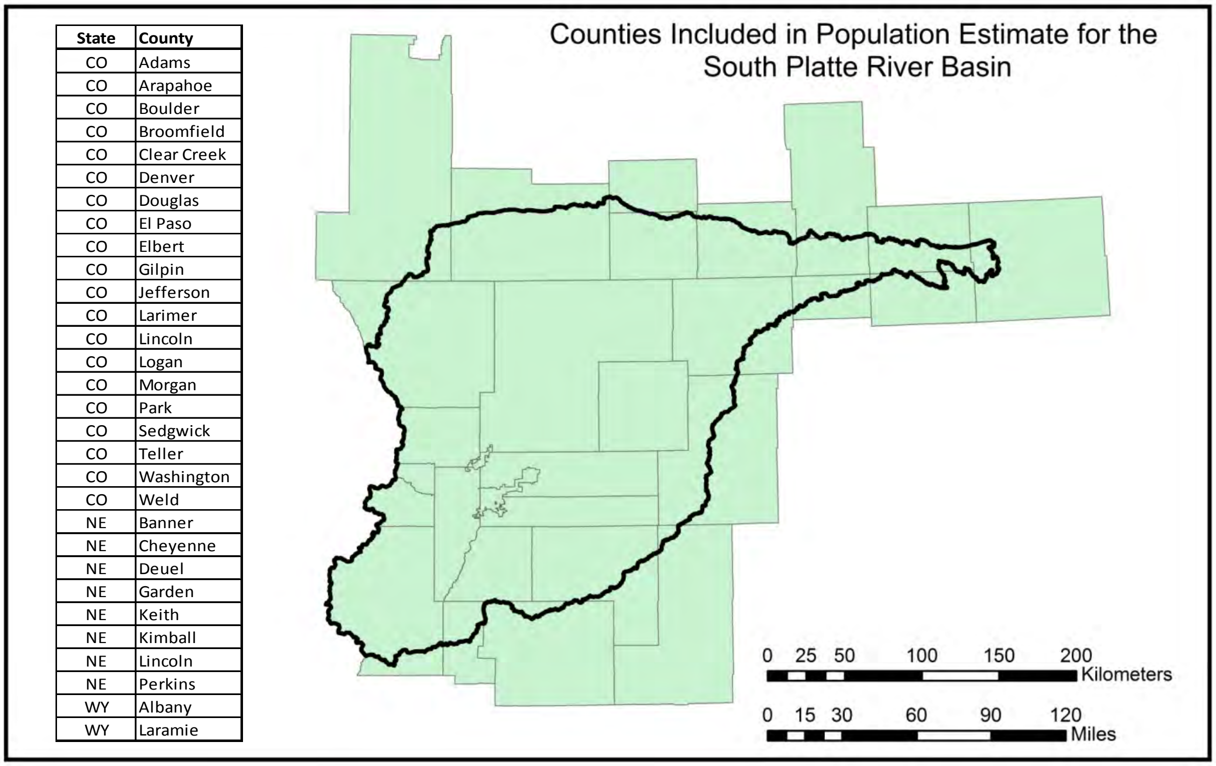

Figure 21: Counties included when calculating estimated population growth by decade under different scenarios within the South Platte River Basin.

Appendix C

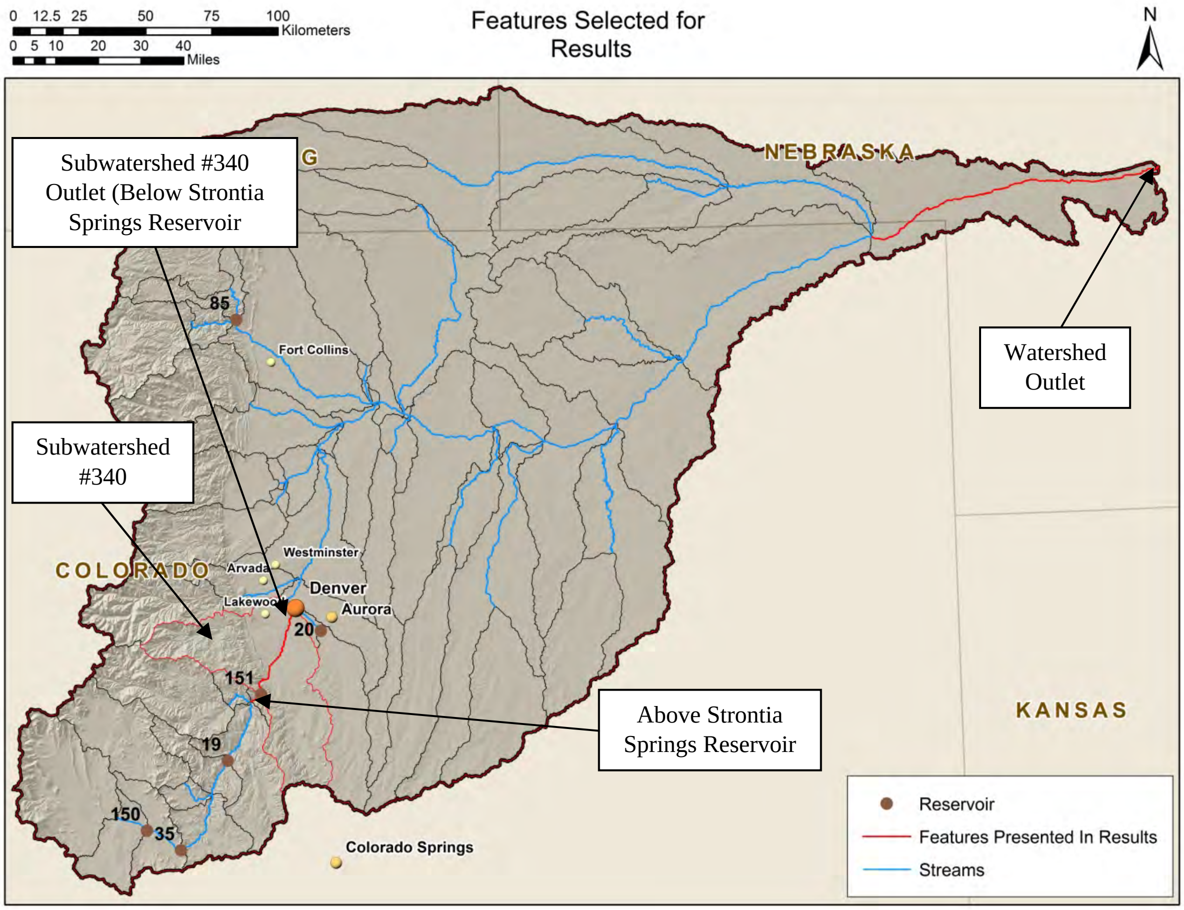

Figure 22: Results presented in this report represent a watershed average as well values for specific streams and subwaterwsheds.

Table 5: 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 (Below Strontia Springs Reservoir)										
Scenario A1	51.2%	3.5%	5.8%	7.0%	7.3%	7.4%	7.5%	7.5%	7.5%	7.5%
Scenario A2	49.9%	3.8%	6.6%	8.2%	8.9%	9.2%	9.3%	9.4%	9.4%	9.5%
Scenario B1	50.2%	2.5%	3.6%	3.9%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
Scenario B2	49.6%	2.4%	3.8%	4.4%	4.6%	4.7%	4.7%	4.7%	4.7%	4.7%
Baseline BC	50.2%	3.4%	5.8%	7.2%	7.9%	8.3%	8.3%	8.4%	8.4%	8.4%
Watershed Average										
Scenario A1	36.8%	0.6%	1.1%	1.3%	1.3%	1.4%	1.4%	1.4%	1.4%	1.4%
Scenario A2	36.7%	0.6%	1.1%	1.3%	1.5%	1.6%	1.6%	1.7%	1.7%	1.8%
Scenario B1	36.7%	0.4%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%
Scenario B2	36.6%	0.4%	0.6%	0.7%	0.7%	0.7%	0.7%	0.8%	0.8%	0.8%
Baseline BC	36.7%	0.6%	0.9%	1.1%	1.3%	1.3%	1.3%	1.3%	1.4%	1.4%

Table 6: Change in Average Annual 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 (Below Strontia Springs Reservoir)										
Scenario A1	119.8 mm	4.3%	8.1%	10.2%	11.3%	11.9%	12.5%	13.0%	13.3%	13.4%
Scenario A2	118.3 mm	3.8%	8.2%	10.8%	12.1%	13.0%	14.2%	15.7%	16.9%	17.6%
Scenario B1	118.8 mm	2.8%	3.8%	4.6%	5.0%	5.4%	5.6%	5.9%	6.2%	6.2%
Scenario B2	118.1 mm	2.5%	3.7%	4.8%	5.3%	5.8%	6.1%	6.6%	7.0%	7.4%
Baseline BC	118.7 mm	3.2%	6.3%	9.1%	10.6%	11.6%	11.9%	12.6%	13.4%	14.8%
Watershed Average										
Scenario A1	90.8 mm	0.8%	1.4%	1.7%	1.8%	1.9%	2.0%	2.1%	2.1%	2.1%
Scenario A2	90.6 mm	0.7%	1.3%	1.7%	1.9%	2.1%	2.2%	2.4%	2.6%	2.7%
Scenario B1	90.7 mm	0.5%	0.7%	0.8%	0.8%	0.9%	0.9%	0.9%	1.0%	1.0%
Scenario B2	90.6 mm	0.5%	0.7%	0.8%	0.9%	0.9%	1.0%	1.0%	1.1%	1.1%
Baseline BC	90.7 mm	0.6%	1.1%	1.4%	1.6%	1.7%	1.8%	1.8%	1.9%	2.0%

Table 7: Change in Channel Average Annual 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	18080 t	2.8%	6.6%	8.6%	9.6%	10.0%	10.5%	11.0%	11.1%	11.2%
Scenario A2	17840 t	2.9%	6.6%	9.3%	10.7%	11.4%	12.2%	13.7%	14.5%	15.1%
Scenario B1	17920 t	1.8%	2.7%	3.1%	3.7%	4.0%	4.3%	4.5%	4.7%	4.9%
Scenario B2	17810 t	2.5%	3.3%	3.5%	3.9%	4.4%	4.8%	5.2%	5.6%	6.0%
Baseline BC	17950 t	2.5%	4.7%	7.5%	8.8%	9.5%	10.1%	10.7%	11.3%	12.8%
Watershed Outlet										
Scenario A1	70740 t	0.6%	1.0%	1.2%	1.5%	1.6%	1.7%	1.8%	1.8%	1.8%
Scenario A2	70660 t	0.5%	0.8%	1.2%	1.5%	1.7%	1.9%	2.2%	2.4%	2.7%
Scenario B1	70660 t	0.4%	0.5%	0.6%	0.7%	0.6%	0.6%	0.6%	0.7%	0.7%
Scenario B2	70620 t	0.4%	0.5%	0.6%	0.7%	0.7%	0.7%	0.7%	0.7%	0.8%
Baseline BC	70670 t	0.5%	0.7%	1.1%	1.3%	1.3%	1.5%	1.5%	1.7%	1.9%

Appendix D

Table 8: Land Cover Change for Scenario A1 from Baseline 2010 to 2100 (*Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parentheses 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	335.9	-4.7 (-1.4%)	-7.0 (-2.1%)	-8.3 (-2.5%)	-8.8 (-2.6%)	-8.9 (-2.6%)	-8.9 (-2.6%)	-8.9 (-2.6%)	-8.9 (-2.6%)	-8.9 (-2.6%)
Perennial Ice/Snow	234.8	0 (0%)	-0.1 (0%)	-0.1 (0%)	-0.1 (0%)	-0.1 (0%)	-0.1 (0%)	-0.1 (0%)	-0.1 (0%)	-0.1 (0%)
Developed, Open Space	1469.6	-37.3 (-2.5%)	-56.5 (-3.8%)	-66.9 (-4.6%)	-70.4 (-4.8%)	-71.4 (-4.9%)	-71.4 (-4.9%)	-71.5 (-4.9%)	-71.6 (-4.9%)	-71.7 (-4.9%)
Developed, Low Intensity	4784.1	297.6 (6.22%)	379.9 (7.9%)	460.2 (9.6%)	427.7 (8.9%)	392.1 (8.2%)	354.6 (7.4%)	321.7 (6.7%)	297.7 (6.2%)	284.6 (6.0%)
Developed, Medium Intensity	1142.3	251.6 (22.0%)	480.6 (42.1%)	536.4 (47.0%)	550.4 (48.2%)	511.3 (44.8%)	441.2 (38.6%)	369.7 (32.4%)	360.2 (31.5%)	351.9 (30.8%)
Developed, High Intensity	913.5	150.9 (16.5%)	297.7 (32.6%)	424.3 (46.5%)	531.7 (58.2%)	634.1 (69.4%)	744.5 (81.5%)	849.6 (93.0%)	884.2 (96.8%)	912.3 (99.9%)
Barren Land	426.6	-2.6 (-0.6%)	-4.6 (-1.1%)	-5.8 (-1.4%)	-6.2 (-1.5%)	-6.4 (-1.5%)	-6.4 (-1.5%)	-6.4 (-1.5%)	-6.4 (-1.5%)	-6.4 (-1.5%)
Deciduous Forest	428.9	-11.1 (-2.6%)	-18.7 (-4.4%)	-22.7 (-5.3%)	-23.7 (-5.5%)	-24.6 (-5.7%)	-24.6 (-5.7%)	-24.6 (-5.7%)	-24.6 (-5.7%)	-25.5 (-6.0%)
Evergreen Forest	7012.1	-95.5 (-1.4%)	-142.2 (-2.0%)	-163.2 (-2.3%)	-172.6 (-2.5%)	-177.8 (-2.5%)	-178.7 (-2.6%)	-178.9 (-2.6%)	-178.9 (-2.6%)	-180.1 (-2.6%)
Mixed Forest	27.8	-0.6 (-2.1%)	-0.8 (-2.7%)	-0.8 (-2.9%)	-0.9 (-3.1%)	-0.9 (-3.2%)	-0.9 (-3.3%)	-0.9 (-3.3%)	-0.9 (-3.3%)	-1.0 (-3.4%)
Scrub/Shrub	2326.8	-62.7 (-2.7%)	-106.1 (-4.6%)	-127.1 (-5.5%)	-132.7 (-5.7%)	-134.1 (-5.8%)	-134.8 (-5.8%)	-134.9 (-5.8%)	-134.9 (-5.8%)	-135.1 (-5.8%)
Grasslands/Herbaceous	27318.6	-187.7 (-0.7%)	-330.6 (-1.2%)	-413.7 (-1.5%)	-437.1 (-1.6%)	-448.0 (-1.6%)	-448.8 (-1.6%)	-449.0 (-1.6%)	-449.1 (-1.6%)	-452.9 (-1.7%)
Pasture/Hay	522.7	-32.2 (-6.2%)	-48.9 (-9.4%)	-57.2 (-11.0%)	-60.0 (-11.5%)	-60.7 (-11.6%)	-60.7 (-11.6%)	-60.7 (-11.6%)	-60.7 (-11.6%)	-60.7 (-11.6%)
Cultivated Crops	13896.2	-240.8 (-1.7%)	-405.5 (-2.9%)	-510.5 (-3.7%)	-551.1 (-4.0%)	-557.5 (-4.0%)	-558.0 (-4.0%)	-558.0 (-4.0%)	-558.7 (-4.0%)	-558.8 (-4.0%)
Woody Wetlands	531.7	-15.4 (-2.9%)	-22.7 (-4.3%)	-26.6 (-5.0%)	-27.6 (-5.2%)	-28.2 (-5.3%)	-28.2 (-5.3%)	-28.2 (-5.3%)	-28.3 (-5.3%)	-28.5 (-5.4%)
Emergent Herbaceous Wetlands	333.5	-9.6 (-2.9%)	-14.9 (-4.5%)	-18.0 (-5.4%)	-18.7 (-5.6%)	-18.9 (-5.7%)	-18.9 (-5.7%)	-18.9 (-5.7%)	-18.9 (-5.7%)	-19.2 (-5.8%)

Table 9: Land Cover Change for Scenario A2 from Baseline 2010 to 2100 (*Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parentheses 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	337.7	-4.7 (-1.4%)	-7.7 (-2.3%)	-9.9 (-2.9%)	-11.0 (-3.3%)	-12.0 (-3.6%)	-12.6 (-3.7%)	-13.2 (-3.9%)	-13.7 (-4.1%)	-14.3 (-4.2%)
Perennial Ice/Snow	234.8	0 (0%)	0 (0%)	-0.1 (0%)	-0.1 (0%)	-0.1 (0%)	-0.1 (0%)	-0.1 (0%)	-0.1 (0%)	-0.1 (0%)
Developed, Open Space	1484.4	-36.9 (-2.5%)	-58.8 (-4.0%)	-74.6 (-5.0%)	-82.8 (-5.6%)	-88.2 (-5.9%)	-91.1 (-6.1%)	-93.9 (-6.3%)	-96.7 (-6.5%)	-100.4 (-6.8%)
Developed, Low Intensity	4666.7	388.8 (8.3%)	407.4 (8.7%)	544.3 (11.7%)	598.5 (12.8%)	571.7 (12.3%)	517.1 (11.1%)	467.3 (10.0%)	406.9 (8.7%)	364.6 (7.8%)
Developed, Medium Intensity	1083.1	163.3 (15.1%)	539.4 (49.8%)	667.8 (61.7%)	713.0 (65.8%)	746.9 (69.0%)	698.8 (64.5%)	534.6 (49.4%)	421.9 (39.0%)	376.2 (34.7%)
Developed, High Intensity	879.6	91.9 (10.4%)	193.1 (22.0%)	293.0 (33.3%)	401.9 (45.7%)	516.6 (58.7%)	697.1 (79.2%)	985.3 (112.0%)	1232.0 (140.1%)	1409.0 (160.2%)
Barren Land	427.1	-2.0 (-0.5%)	-3.9 (-0.9%)	-5.2 (-1.2%)	-6.0 (-1.4%)	-6.5 (-1.5%)	-6.8 (-1.6%)	-7.0 (-1.6%)	-7.1 (-1.7%)	-7.4 (-1.7%)
Deciduous Forest	431.9	-10.9 (-2.5%)	-19.0 (-4.4%)	-23.8 (-5.5%)	-25.8 (-6.0%)	-26.8 (-6.2%)	-27.4 (-6.4%)	-27.7 (-6.4%)	-28.3 (-6.6%)	-28.8 (-6.7%)
Evergreen Forest	7028.6	-90.8 (-1.3%)	-146.1 (-2.1%)	-177.5 (-2.5%)	-190.7 (-2.7%)	-202.4 (-2.9%)	-208.2 (-3.0%)	-211.5 (-3.0%)	-217.2 (-3.1%)	-222.5 (-3.2%)
Mixed Forest	28.0	-0.6 (-2.3%)	-0.9 (-3.1%)	-1.0 (-3.6%)	-1.0 (-3.7%)	-1.1 (-4.0%)	-1.1 (-4.0%)	-1.1 (-4.1%)	-1.2 (-4.4%)	-1.2 (-4.4%)
Scrub/Shrub	2344.8	-60.1 (-2.6%)	-108.4 (-4.6%)	-138.9 (-5.9%)	-153.7 (-6.6%)	-160.4 (-6.8%)	-164.6 (-7.0%)	-166.9 (-7.1%)	-169.2 (-7.2%)	-172.3 (-7.4%)
Grasslands/Herbaceous	27376.5	-175.2 (-0.6%)	-320.8 (-1.2%)	-423.2 (-1.6%)	-476.3 (-1.7%)	-501.9 (-1.8%)	-520.0 (-1.9%)	-536.1 (-2.0%)	-551.8 (-2.0%)	-567.8 (-2.1%)
Pasture/Hay	532.3	-29.2 (-5.5%)	-50.3 (-9.5%)	-62.9 (-11.8%)	-70.4 (-13.2%)	-74.8 (-14.1%)	-77.8 (-14.6%)	-81.0 (-15.2%)	-84.1 (-15.8%)	-87.8 (-16.5%)
Cultivated Crops	13976.0	-209.0 (-1.5%)	-384.9 (-2.8%)	-538.8 (-3.9%)	-641.7 (-4.6%)	-704.7 (-5.0%)	-745.1 (-5.3%)	-789.2 (-5.7%)	-830.1 (-5.9%)	-883.5 (-6.3%)
Woody Wetlands	536.7	-15.2 (-2.8%)	-24.0 (-4.5%)	-29.7 (-5.5%)	-32.3 (-6.0%)	-33.6 (-6.3%)	-34.6 (-6.4%)	-35.3 (-6.6%)	-36.1 (-6.7%)	-37.4 (-7.0%)
Emergent Herbaceous Wetlands	336.7	-9.3 (-2.8%)	-15.1 (-4.5%)	-19.6 (-5.8%)	-21.6 (-6.4%)	-22.8 (-6.8%)	-23.7 (-7.0%)	-24.4 (-7.3%)	-25.2 (-7.5%)	-26.3 (-7.8%)

Table 10: Land Cover Change for Scenario B1 from Baseline 2010 to 2100 (*Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parentheses 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	336.8	-3.4 (-1.0%)	-4.5 (-1.3%)	-5.0 (-1.5%)	-5.1 (-1.5%)	-5.1 (-1.5%)	-5.1 (-1.5%)	-5.1 (-1.5%)	-5.1 (-1.5%)	-5.1 (-1.5%)
Perennial Ice/Snow	234.8	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Developed, Open Space	1473.7	-26.0 (-1.8%)	-35.2 (-2.4%)	-39.0 (-2.7%)	-39.4 (-2.7%)	-39.5 (-2.7%)	-39.5 (-2.7%)	-39.5 (-2.7%)	-39.5 (-2.7%)	-39.5 (-2.7%)
Developed, Low Intensity	4691.9	256.6 (5.5%)	326.9 (7.0%)	274.9 (5.9%)	199.9 (4.3%)	161.2 (3.4%)	127.8 (2.7%)	101.6 (2.2%)	75.8 (1.6%)	56.0 (1.2%)
Developed, Medium Intensity	1110.8	75.9 (6.8%)	94.4 (8.5%)	140.4 (12.6%)	148.7 (13.4%)	107.8 (9.7%)	67.4 (6.1%)	18.5 (1.7%)	-16.9 (-1.5%)	-43.3 (-3.9%)
Developed, High Intensity	906.2	124.7 (13.8%)	223.2 (24.6%)	299.2 (33.0%)	372.3 (41.1%)	453.0 (50.0%)	526.9 (58.1%)	601.9 (66.4%)	663.1 (73.2%)	709.3 (78.3%)
Barren Land	426.9	-1.5 (-0.4%)	-2.2 (-0.5%)	-2.5 (-0.6%)	-2.6 (-0.6%)	-2.6 (-0.6%)	-2.6 (-0.6%)	-2.6 (-0.6%)	-2.6 (-0.6%)	-2.6 (-0.6%)
Deciduous Forest	432.1	-7.1 (-1.6%)	-9.9 (-2.3%)	-10.7 (-2.5%)	-10.8 (-2.5%)	-10.9 (-2.5%)	-10.9 (-2.5%)	-10.9 (-2.5%)	-10.9 (-2.5%)	-10.9 (-2.5%)
Evergreen Forest	7027.7	-55.2 (-0.8%)	-76.3 (-1.1%)	-79.9 (-1.1%)	-80.0 (-1.1%)	-80.0 (-1.1%)	-80.0 (-1.1%)	-80.0 (-1.1%)	-80.0 (-1.1%)	-80.0 (-1.1%)
Mixed Forest	27.9	-0.4 (-1.3%)	-0.4 (-1.6%)	-0.4 (-1.6%)	-0.4 (-1.6%)	-0.4 (-1.6%)	-0.4 (-1.6%)	-0.4 (-1.6%)	-0.4 (-1.6%)	-0.4 (-1.6%)
Scrub/Shrub	2341.6	-37.2 (-1.6%)	-54.0 (-2.3%)	-61.2 (-2.6%)	-61.6 (-2.6%)	-61.8 (-2.6%)	-61.8 (-2.6%)	-61.8 (-2.6%)	-61.8 (-2.6%)	-61.8 (-2.6%)
Grasslands/Herbaceous	27360.6	-125.4 (-0.5%)	-177.2 (-0.7%)	-196.5 (-0.7%)	-198.1 (-0.7%)	-198.8 (-0.7%)	-198.8 (-0.7%)	-198.8 (-0.7%)	-198.8 (-0.7%)	-198.8 (-0.7%)
Pasture/Hay	528.5	-19.7 (-3.7%)	-27.1 (-5.1%)	-30.8 (-5.8%)	-31.1 (-5.9%)	-31.1 (-5.9%)	-31.1 (-5.9%)	-31.1 (-5.9%)	-31.1 (-5.9%)	-31.1 (-5.9%)
Cultivated Crops	13935.3	-165.3 (-1.2%)	-234.8 (-1.7%)	-263.3 (-1.9%)	-266.7 (-1.9%)	-266.9 (-1.9%)	-266.9 (-1.9%)	-266.9 (-1.9%)	-266.9 (-1.9%)	-266.9 (-1.9%)
Woody Wetlands	534.6	-10.1 (-1.9%)	-14.2 (-2.7%)	-15.3 (-2.9%)	-15.4 (-2.9%)	-15.4 (-2.9%)	-15.4 (-2.9%)	-15.4 (-2.9%)	-15.4 (-2.9%)	-15.4 (-2.9%)
Emergent Herbaceous Wetlands	335.6	-6.1 (-1.8%)	-8.7 (-2.6%)	-9.6 (-2.9%)	-9.7 (-2.9%)	-9.7 (-2.9%)	-9.7 (-2.9%)	-9.7 (-2.9%)	-9.7 (-2.9%)	-9.7 (-2.9%)

Table 11: **Land Cover Change for Scenario B2 from Baseline 2010 to 2100 (*Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parentheses 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	337.9	-3.9 (-1.1%)	-5.2 (-1.5%)	-5.9 (-1.7%)	-6.5 (-1.9%)	-6.6 (-2.0%)	-6.7 (-2.0%)	-6.7 (-2.0%)	-6.7 (-2.0%)	-6.7 (-2.0%)
Perennial Ice/Snow	234.8	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Developed, Open Space	1484.8	-28.6 (-1.9%)	-41.9 (-2.8%)	-47.6 (-3.2%)	-50.4 (-3.4%)	-52.1 (-3.5%)	-52.8 (-3.6%)	-53.3 (-3.6%)	-53.5 (-3.6%)	-53.5 (-3.6%)
Developed, Low Intensity	4618.3	284.5 (6.2%)	398.8 (8.6%)	365.6 (7.9%)	326.4 (7.1%)	261.9 (5.7%)	202.9 (4.4%)	148.8 (3.2%)	97.6 (2.1%)	48.0 (1.0%)
Developed, Medium Intensity	1085.5	90.4 (8.3%)	122.8 (11.3%)	196.1 (18.1%)	232.2 (21.4%)	254.5 (23.5%)	235.7 (21.7%)	195.8 (18.0%)	127.7 (11.8%)	69.9 (6.4%)
Developed, High Intensity	881.1	83.3 (9.5%)	165.4 (18.8%)	238.4 (27.1%)	298.7 (33.9%)	362.6 (41.2%)	448.9 (50.9%)	547.3 (62.1%)	669.3 (76.0%)	777.4 (88.2%)
Barren Land	427.7	-1.8 (-0.4%)	-2.6 (-0.6%)	-2.9 (-0.7%)	-3.3 (-0.8%)	-3.3 (-0.8%)	-3.3 (-0.8%)	-3.4 (-0.8%)	-3.4 (-0.8%)	-3.4 (-0.8%)
Deciduous Forest	433.5	-7.3 (-1.7%)	-10.3 (-2.4%)	-11.6 (-2.7%)	-12.0 (-2.8%)	-12.2 (-2.8%)	-12.3 (-2.8%)	-12.3 (-2.9%)	-12.4 (-2.9%)	-12.4 (-2.9%)
Evergreen Forest	7038.9	-57.1 (-0.8%)	-82.1 (-1.2%)	-88.0 (-1.3%)	-89.4 (-1.3%)	-90.0 (-1.3%)	-90.2 (-1.3%)	-90.5 (-1.3%)	-90.9 (-1.3%)	-91.5 (-1.3%)
Mixed Forest	28.0	-0.4 (-1.3%)	-0.5 (-1.7%)	-0.5 (-1.8%)	-0.5 (-1.8%)	-0.5 (-1.8%)	-0.5 (-1.8%)	-0.5 (-1.8%)	-0.5 (-1.8%)	-0.5 (-1.8%)
Scrub/Shrub	2351.1	-36.6 (-1.6%)	-58.0 (-2.5%)	-67.4 (-2.9%)	-71.7 (-3.1%)	-73.2 (-3.1%)	-74.1 (-3.2%)	-74.6 (-3.2%)	-74.9 (-3.2%)	-74.9 (-3.2%)
Grasslands/Herbaceous	27394.7	-127.2 (-0.5%)	-192.3 (-0.7%)	-220.0 (-0.8%)	-232.6 (-0.9%)	-237.4 (-0.9%)	-240.5 (-0.9%)	-242.0 (-0.9%)	-242.9 (-0.9%)	-243.0 (-0.9%)
Pasture/Hay	534.3	-20.2 (-3.8%)	-29.4 (-5.5%)	-35.0 (-6.5%)	-38.5 (-7.2%)	-39.8 (-7.5%)	-40.0 (-7.5%)	-40.0 (-7.5%)	-40.1 (-7.5%)	-40.1 (-7.5%)
Cultivated Crops	13978.7	-157.4 (-1.1%)	-239.4 (-1.7%)	-292.3 (-2.1%)	-322.1 (-2.3%)	-332.7 (-2.4%)	-335.7 (-2.4%)	-337.3 (-2.4%)	-338.1 (-2.4%)	-338.1 (-2.4%)
Woody Wetlands	538.1	-11.4 (-2.1%)	-16.0 (-3.0%)	-18.1 (-3.4%)	-18.9 (-3.5%)	-19.3 (-3.6%)	-19.3 (-3.6%)	-19.4 (-3.6%)	-19.4 (-3.6%)	-19.4 (-3.6%)
Emergent Herbaceous Wetlands	337.5	-6.4 (-1.9%)	-9.3 (-2.8%)	-10.9 (-3.2%)	-11.6 (-3.4%)	-11.8 (-3.5%)	-11.9 (-3.5%)	-11.9 (-3.5%)	-11.9 (-3.5%)	-11.9 (-3.5%)

Table 12: Land Cover Change for Baseline BC from Baseline 2010 to 2100 (*Note: Largest Positive/Negative Changes are Highlighted Red/Orange; values in parentheses 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	337.2	-4.6 (-1.4%)	-6.9 (-2.0%)	-8.9 (-2.6%)	-10.1 (-3.0%)	-10.7 (-3.2%)	-11.0 (-3.7%)	-11.2 (-3.3%)	-11.3 (-3.4%)	-11.4 (-3.4%)
Perennial Ice/Snow	234.8	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Developed, Open Space	1480.0	-34.2 (-2.3%)	-53.8 (-3.6%)	-68.0 (-4.6%)	-75.2 (-5.2%)	-78.6 (-5.3%)	-80.4 (-5.4%)	-81.9 (-5.5%)	-82.5 (-5.6%)	-82.5 (-5.6%)
Developed, Low Intensity	4710.6	407.3 (8.7%)	500.6 (10.6%)	524.1 (11.1%)	544.0 (11.6%)	534.4 (11.3%)	491.4 (10.4%)	433.1 (9.2%)	369.9 (7.9%)	301.0 (6.4%)
Developed, Medium Intensity	1092.0	111.5 (10.2%)	342.0 (31.3%)	546.0 (50.0%)	617.7 (56.6%)	632.3 (57.9%)	624.7 (57.2%)	596.2 (54.6%)	518.5 (47.5%)	350.7 (32.1%)
Developed, High Intensity	882.9	90.2 (10.2%)	181.2 (20.5%)	264.2 (29.9%)	339.9 (38.5%)	415.5 (47.1%)	510.9 (57.9%)	622.9 (70.6%)	776.6 (88.0%)	1016.2 (115.1%)
Barren Land	427.0	-1.9 (-0.4%)	-3.5 (-0.8%)	-4.8 (-1.1%)	-5.8 (-1.4%)	-6.0 (-1.4%)	-6.1 (-1.4%)	-6.1 (-1.4%)	-6.2 (-1.4%)	-6.2 (-1.5%)
Deciduous Forest	431.0	-9.7 (-2.3%)	-15.8 (-3.7%)	-19.6 (-4.5%)	-21.6 (-5.0%)	-22.4 (-5.2%)	-22.6 (-5.3%)	-22.8 (-5.3%)	-22.9 (-5.3%)	-22.9 (-5.3%)
Evergreen Forest	7025.5	-81.1 (-1.2%)	-122.3 (-1.7%)	-145.0 (-2.1%)	-153.3 (-2.2%)	-156.5 (-2.2%)	-157.6 (-2.2%)	-158.2 (-2.3%)	-158.6 (-2.3%)	-158.8 (-2.3%)
Mixed Forest	27.9	-0.6 (-2.2%)	-0.8 (-2.8%)	-0.9 (-3.1%)	-0.9 (-3.1%)	-0.9 (-3.2%)	-0.9 (-3.2%)	-0.9 (-3.2%)	-0.9 (-3.2%)	-0.9 (-3.2%)
Scrub/Shrub	2341.5	-56.0 (-2.4%)	-95.9 (-4.1%)	-122.5 (-5.2%)	-134.9 (-5.8%)	-139.2 (-5.9%)	-140.5 (-6.0%)	-141.3 (-6.0%)	-141.5 (-6.0%)	-141.6 (-6.1%)
Grasslands/Herbaceous	27364.4	-160.7 (-0.6%)	-278.1 (-1.0%)	-359.7 (-1.3%)	-400.2 (-1.5%)	-419.2 (-1.5%)	-428.9 (-1.6%)	-435.1 (-1.6%)	-437.9 (-1.6%)	-438.8 (-1.6%)
Pasture/Hay	529.7	-28.7 (-5.4%)	-47.1 (-8.9%)	-58.9 (-11.1%)	-65.2 (-12.3%)	-67.8 (-12.8%)	-69.5 (-13.1%)	-70.3 (-13.3%)	-71.1 (-13.4%)	-71.3 (-13.5%)
Cultivated Crops	13948.7	-207.9 (-1.5%)	-364.1 (-2.6%)	-502.2 (-3.6%)	-587.2 (-4.2%)	-631.9 (-4.5%)	-659.6 (-4.7%)	-673.9 (-4.8%)	-681.5 (-4.9%)	-682.9 (-4.9%)
Woody Wetlands	535.8	-14.8 (-2.8%)	-22.1 (-4.1%)	-26.9 (-5.0%)	-28.8 (-5.4%)	-29.6 (-5.5%)	-30.0 (-5.6%)	-30.3 (-5.7%)	-30.4 (-5.7%)	-30.4 (-5.7%)
Emergent Herbaceous Wetlands	335.9	-8.9 (-2.7%)	-13.5 (-4.0%)	-16.9 (-5.0%)	-18.6 (-5.5%)	-19.4 (-5.8%)	-19.9 (-5.9%)	-20.1 (-6.0%)	-20.2 (-6.0%)	-20.2 (-6.0%)

References

Arnold, J.G., Williams, J.R., Srinivasan, R., King, K.W. and Griggs, R.H. 1994. SWAT: Soil Water Assessment Tool. U. S. Department of Agriculture, Agricultural Research Service, Grassland, Soil and Water Research Laboratory, Temple, TX.

Bierwagen, B.G., Theobald, D.M., Pyke, C.R., Choate, A., Groth, P., Thomas, J.V., and Morefield, P. 2010. National Housing and Impervious Surface Scenarios for Integrated Climate Impact Assessments. Proceedings of the National Academy of Sciences of the United States of America. Vol. 107, No. 49 20887-20892.

Brauman, K.A., Daily, G.C., Duarte, T.K., and Mooney, H.A. 2007. The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services. Annual Review of Environmental Resources 32:67–98.

Burns, I.S., Kepner, W.G., Sidman, G.S., Goodrich, D.C., Guertin, D.P., Levick, L.R., Yee, W.W.S, Scianni, M.M.A., Meek, C.S., and Vollmer, J.B. 2013. Assessing Hydrologic Impacts of Future Land Cover Change Scenarios in the San Pedro River (U.S./Mexico). U.S. Environmental Protection Agency ORD and USDA/ARS, EPA/600/R-13/074, ARS/294076. 52pp.

Caulfield, H.R. Jr., Evans, N.A., Flack, J.E., Grigg, N.S., Hendricks, D.W., Labadie, J.W., McWhorter, D., Morel-Seytoux, H.J., Raley, W.L., Young, R.A., and Milliken, J.G. 1987. Voluntary Basinwide Water Management: South Platte River Basin Colorado. Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO. 161 pp.

CDSS, 2014. Colorado’s Decision Support Systems. http://cdss.state.co.us/onlineTools/Pages/StructuresDiversions.aspx/, Accessed February 2014.

Chapin, F.S., Matson, P.A., and Mooney, H.A. 2002. Principles of Terrestrial Ecosystem Ecology. Springer Science, New York, New York, USA.

Daniel, E.B., Camp, J.V., LeBoueuf, E.F., Penrod, J.R., Dobbins, J.P., and Abkowitz, M.D. 2011. Watershed Modeling and its Applications: A State-of-the-Art Review. The Open Hydrology Journal 5:26–50.

DeFries, R.S., and Eshleman, K.N. 2004. Land-use Change and Hydrologic Processes: A Major Focus for the Future. Hydrological Processes 18:2183–2186.

Dennehy, K.F., Litke, D.W., Tate, C.M, and Heiny, J.S. 1993. South Platte River Basin – Colorado, Nebraska, and Wyoming. American Water Resources Association: Water Resources Bulletin. Vol 29(4): 647-683.

Ebert, D.W., and Wade, T.G. 2004. Analytical Tools Interface for Landscape Assessments (ATtILA). EPA, Office of Research and Development, National Exposure Research

Laboratory, Environmental Sciences Division, Landscape Ecology Branch, Las Vegas, NV (EPA/600/R-04/083), 39 pp.

Eschner, T.R., Hadley, R.F., and Crowley, K.D. 1983. Hydrologic and Morphologic Changes in Channels of the Platte River Basin in Colorado, Wyoming, and Nebraska: A Historical Perspective. Hydrologic and Geomorphic Studies of the Platte River Basin: Geologic Survey Professional Paper 1277-A.

Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J. 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77(9):858-864.

Fuka, D.R., Walter, M.T., MacAlister, C., Degaetano, A.T., Steenhuis, T.S., and Easton, Z.M. 2013. Using the Climate Forecast System Reanalysis as Weather Input Data for Watershed Models. Hydrological Processes 11pp.

Globalweather, 2014. NCEP Climate Forecast System Reanalysis (CFRS). http://globalweather.tamu.edu/, Accessed May 2014.

Goodrich DC, Burns IS, Unkrich CL, Semmens DJ, Guertin DP, Hernandez M, Yatheendradas S, Kennedy JR, Levick LR (2012) KINEROS2/AGWA: Model Use, Calibration, and Validation. *Transactions of the ASABE* **55**(4), 1561-1574

Guy, R.K., Boykin, K.G., Kepner, W.G., and McCarthy, J.M. 2011. South Platte River Basin Data Browser. EPA/600/R-12/001. 9 Pp.

Guy, R.K., Boykin, K.G., Kepner, W.G., and McCarthy, J.M. 2011. South Platte River Basin Data Browser. EPA/600/C-12/0001. http://case.nmsu.edu/CASE/SouthPlatte/index.htm

IPCC (2001) Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge University Press, Cambridge, UK) p 881.

Jin, S., Yang, L., Danielson, P., Homer, C., Fry, J., and Xian, G. 2013. A Comprehensive Change Detection Method for Updating the National Land Cover Database to circa 2011 Remote Sensing of Environment,. 132: 159 – 175. http://www.mrlc.gov/nlcd2011.php

Johnson, T.E., Butcher, J.B, Parker, A., and Weaver, C.P. 2012. Investigating the Sensitivity of U.S. Streamflow and Water Quality to Climate Change: The U.S. EPA Global Change Research Program's "20 Watersheds" Project. J. Water Resour. Plann. Manage. 2012.138:453-464.

Kepner, W.G., Ramsey, M.M., Brown, E.S., Jarchow, M.E., Dickinson, K.J.M., and Mark, A.F. 2012. Hydrologic Futures: Using Scenario Analysis to Evaluate Impacts of Forecasted Land Use Change on Hydrologic Services. Ecosphere Volume 3:7 Article 69. 25 pp. http://www.esajournals.org/doi/pdf/10.1890/ES11-00367.1

Kircher, J.E. and Karlinger, M.R. 1983. Effects of Water Development on Surface-Water Hydrology, Platte River Basin in Colorado, Wyoming, and Nebraska Upstream from

Duncan, Nebraska. Hydrologic and Geomorphic Studies of the Platte River Basin: Geologic Survey Professional Paper 1277-A.

Liu, Y., Gupta, H., Springer, E., and Wagener, T. 2008a. Linking Science with Environmental Decision Making: Experiences from an Integrated Modeling Approach to Supporting Sustainable Water Resources Management. Environmental Modelling and Software 23:846–858.

Liu, Y., Mahmoud, M., Hartmann, H., Stewart, S., Wagener, T., Semmens, D.J., Stewart, R., Gupta, H., Dominguez, D., Hulse, D., Letcher, R., Rashleigh, B., Street, R., Ticehurst, J., Twery, M., Van Delden, H., Waldick, R., White, D., Winter, L., and Smith, C. 2008b. Formal Scenario Development for Environmental Impact Assessment Studies. Chapter 9, A. Jakeman, A. Voinov, A. Rizzoli, and S. Chen (ed.), Environmental Modelling, Software and Decision Support. Elsevier Science, New York, NY, pp. 145-162.

Mau, D.P. and Christensen, V.G. 2000. Comparison of Sediment Deposition in Reservoirs of Four Kansas Watersheds. USGS Fact Sheet102-00.

Mahmoud M., Liu, Y., Hartmann, H., Stewart, S., Wagener, T., Semmens, D., Stewart, R., Gupta, H., Dominguez, D., Dominguez, F., Hulse, D., Letcher, R., Rashleigh, B., Smith, C., Street, R., Ticehurst, J., Twery, M., van Delden, H., Waldick, R., White, D., and Winter, L. 2009. A formal framework for scenario development in support of environmental decision-making. Environmental Modeling & Software 24:798-808.

March, H., Therond, O., and Leenhardt, D. 2012. Water Futures: Reviewing Water-scenario Analyses through an Original Interpretative Framework. Ecological Economics 82 (2012) 126–137.

Miller, S.N., Semmens, D.J., Goodrich, D.C., Hernandez, M., Miller, R.C., Kepner, W.G., and Guertin, D.P. 2007. The Automated Geospatial Watershed Assessment Tool. Environmental Modelling & Software, 22(3):365-377.

Naiman, R.J. and Décamps, H. 1997. The Ecology of Interfaces: Riparian Zones. Annual Review of Ecology and Systematics. Vol. 28. Pp. 621-658.

Nakicenovic N., and Swart R., Eds. 2000. Special Report on Emissions Scenarios (Cambridge University Press, Cambridge, UK) p 570.

Narasimhan, B., Srinivasan, R., Bednarz, S.T., Ernst, M.R., Allen, P.M. 2010. A Comprehensive Modeling Approach for Reservoir Water Quality Assessment and Management Due to Point and Nonpoint Source Pollution. American Society of Agricultural and Biological Engineers. Vol 53 (5):1605-1617.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., and King, K.W. 2002. "Soil and Water Assessment Tool Theoretical Documentation, Version 2000." USDA Agricultural Research Service (ARS) Grassland, Soil and Water Research Laboratory, Texas Agricultural Experiment Station, Blackland Research Center, Temple, TX.

Novitzki, R.P., Smith, R.D., and Fretwell, J.D. 1997. Restoration, Creation, and Recovery of Wetlands: Wetland Function, Values, and Assessments. United States Geological Survey Water Supply Paper 2425 < http://water.usgs.gov/nwsum/WSP2425/functions.html>

Pyke, C., Warren, M.P., Johnson, T., LaGro, J., Scharfenberg, J., Groth, P., Freed, R., Schroeer, W., and Main, E. 2011. Assessment of Low Impact Development for Managing Stormwater with Changing Precipitation due to Climate Change. Landscape and Urban Planning 103: 166-173.

Rapport, D.J., Gaudet, C., Karr, J.R., Baron, J.S., Bohlen, C., Jackson, W., Jones, B., Naiman, R.J., Norton, B., and Pollock, M.M. 1998. Evaluating Landscape Health: Integrating Societal Goals and Biophysical Processes. Journal of Environmental Management. 53:1-15.

Ruddy, B.C., and Hitt, K.J. 1990. Summary of Selected Characteristics of Large Reservoirs in the United States and Puerto Rico, 1988. U.S. Geologic Survey: Open-File Report 90-163.

Saha, S., et al. 2010. NCEP Climate Forecast System Reanalysis (CFSR) 6-hourly Products, January 1979 to December 2010. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. http://dx.doi.org/10.5065/D69K487J. Accessed 23 May 2013.

Saunders, W., 1999. Preparation of DEMs for Use in Environmental Modeling Analysis. Esri User Conference, San Diego, CA, 1999. http://proceedings.esri.com/library/userconf/proc99/proceed/papers/pap802/p802.htm

Saunders, J.F. and Lewis, W.M. Jr. 2003. Implications of Climatic Variability for Regulatory Low Flows in the South Platte River Basin, Colorado. Journal of the American Water Resources Association. 39(1):33-45.

Semmens D.J., Goodrich, D.C., Unkrich, C.L., Smith, R.E., Woolhiser, D.A., Miller, S.N. 2008. KINEROS2 and the AGWA Modelling Framework. In: Hydrological Modelling in Arid and Semi-Arid Areas. London: Cambridge University Press. pp. 49-69.

Srinivasan, R., and Arnold, J.G. 1994. Integration of a Basin-scale Water Quality Model with GIS. Journal of American Water Resources Association, 30, 453-462.

Steinitz, C., Arias, H., Bassett, S., Flaxman, M., Goode, T., Maddock T. III, Mouat, D., Peiser, R. and Shearer, A. 2003. Alternative Futures for Changing Landscapes. The Upper San Pedro River Basin in Arizona and Sonora, Island Press, Washington, DC, USA.

Strange, E.M., Fausch, K.D., and Covich, A.P. 1999. Sustaining Ecosystem Services in Human-Dominated Watersheds: Biohydrology and Ecosystem Processes in the South Platte River Basin. Environmental Management. Vol 24 (1):39-54.

Triantakonstantis, D. and Mountrakis, G. 2012. Urban Growth Prediction: A Review of Computational Models and Human Perceptions. J. Geographic Information System 4:555-587.

Tuppad, P., Douglas-Mankin, K.R., Lee, T., Srinivasan, R., and Arnold, J.G. 2011. Soil and Water Assessment Tool (SWAT) hydrologic/water quality model: Extended capability and wider adoption. *Transactions of the ASABE*. 54(5): 1677-1684.

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS) 1994. State Soil Geographic (STATSGO) Data Base: Data Use Information, National Cartography and GIS Center, Fort Worth, Texas.

U.S. Department of the Interior (USDI), Bureau of Reclamation 2012. Colorado River Basin Water Supply and Demand Study (Study Report and Technical Reports A-G). http://www.usbr.gov/lc/region/programs/crbstudy/finalreport/index.html.

U.S. EPA Office of Research & Development (ORD). 2007. ICLUS v 1.3 Population Projections. National Center for Environmnetal Assessment. http://edg.epa.gov/data/Public/ORD/NCEA/county_pop.zip

U.S. Environmental Protection Agency (EPA) 2009. Land-Use Scenarios: National-Scale Housing-Density Scenarios Consistent with Climate Change Storylines. U.S. Environmental Protection Agency, Global Change Research Program, National Center for Environmental Assessment, Washington, DC. EPA/600/R-08/076F (http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=203458).

U.S. Environmental Protection Agency (EPA) 2010. ICLUS V1.3 User's Manual: ARCGIS Tools for Modeling U.S. Housing Density Growth. U.S. Environmental Protection Agency, Global Change Research Program, National Center for Environmental Assessment, Washington, DC. EPA/600/R-09/143F (http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=205305).

van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S.J., Rose, S.K. 2011. The Representative Concentration Pathways : an Overview. Climate Change 109: 5-31.

Vitousek, P.M. 1994. Beyond Global Warming: Ecology and Global Change. Ecology 75(7):1861–1876.

Vörösmarty, J., Green, P., Salisbury, J., Lammers, R.B. 2000. Global Water Resources: Vulnerability from Climate Change and Population Growth. Science 289, 284–288.

Whitehead, P.G., Wilby, R.L., Battarbee, R.W., Kernan, M., and Wade, A.J. (2009). "A Review of the Potential Impacts of Climate Change on Surface Water Quality." Hydrol. Sci., 54(1), 101–123

United States
Environmental Protection
Agency

Please make all necessary changes on the below label, detach or copy and return to the address in the upper left hand corner.

If you do not wish to receive these reports CHECK HERE ☐; detach, or copy this cover, and return to the address in the upper left hand corner.

PRESORTED STANDARD
POSTAGE & FEES PAID
EPA PERMIT No. G-35

Office of Research
and Development (8101R)
Washington, DC 20460

Official Business
Penalty for Private Use
$300

EPA/600/R-14/328
ARS/309194
September 2014
www.epa.gov

Recycled/Recyclable
Printed with vegetable-based ink on paper that contains a minimum of 50% post-consumer fiber content processed chlorine free