TECHNICAL REPORT: QUANTITATIVE DEMONSTRATION HEALTH IMPACT ASSESSMENTS IN THREE NORTH CAROLINA COMMUNITIES

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In 2012-2013, the North Carolina Department of Transportation updated its Statewide Bicycle and Pedestrian Master Plan, known as *WalkBikeNC*. The plan contains five "pillars" that relate to bicycling and pedestrian transportation: mobility, safety, health, economy and environment. As part of the Health component of *WalkBikeNC*, this report summarizes the projected health impacts following pedestrian and bicycle project implementation in three North Carolina communities.

Health Impact Assessment (HIA) is a powerful tool for communicating to decision-makers the value of investments that support improved health outcomes. However, HIA practice in the United States often relies heavily on qualitative methods that may have limited relevance to decision-making processes, particularly in sectors that have developed highly technical decision-making practices, such as transportation.[1] Further, transportation agencies are facing pressure from funding scarcity and federal policy directives, including the recently re-authorized federal transportation funding bill, MAP-21, to demonstrate the value of transportation investments.[2,3] Quantitative HIA methods provide a means for placing an economic value on health impacts, allowing transportation agencies to demonstrate the value of transportation investments that support an active lifestyle and enabling decision-makers to consider such investments in a cost-benefit analysis framework.[4] To demonstrate the ability of HIA to quantitatively estimate the health impacts of active transportation[a] infrastructure, including construction of new sidewalks, streetscape improvements, and improved pedestrian crossings, we conduct three HIAs on pedestrian improvements throughout North Carolina focusing on state-of-the-art quantitative modeling methods.

The HIA process includes six consecutive stages: 1) Screening; 2) Scoping; 3) Assessment, 4) Recommendations, 5) Reporting; and 6) Monitoring and Evaluation. During the Screening stage, the HIA is broadly defined and it is determined whether or not the HIA is likely to succeed and add value. Scoping includes data collection, stakeholder outreach, and preliminary research to outline and establish goals for the HIA. Health impacts relative to baseline conditions are estimated during the Assessment stage, and the results are translated into useful units and disseminated during the Recommendations and Reporting stages. Monitoring and Evaluation includes an objective assessment of the quality of the HIA performed, the efficacy of the HIA in influencing future decisions, and outcome assessment once the project has been completed and health impacts are observable in the population.[5] We complete the first four stages of this process in this HIA and prospectively discuss reporting, monitoring, and evaluation. Our principle aim is to apply quantitative methods to estimate the health impacts, and related economic implications, of investments in pedestrian amenities in three North Carolina communities.

Screening

As part of the overall Health component of WalkBikeNC, a Health Advisory Team was formed to help establish goals and provide guidance for the HIA demonstration component of the plan. The Health Advisory Team was co-

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[a] Active transportation includes walking and biking for transportation, and walking or biking to/from public transit

led by staff members at Active Living By Design and the Department of Environmental Sciences and Engineering at the Gillings School of Global Public Health at UNC-CH. A full list of team members and affiliations appears in Appendix 1 of this report.

The Health Advisory Team met three times to provide guidance to researchers at UNC-CH. The principal aim of the project – to demonstrate quantitative HIA methods applied to active transportation infrastructure improvements in a variety of contexts throughout North Carolina – was defined during the initial meeting. After developing a list of candidate projects to undergo demonstration HIAs, the Health Advisory Team helped develop several selection criteria to screen projects and develop a final list of three projects. We chose projects so that three development contexts would be represented (urban, suburban, and rural), three project scales would be represented (comprehensive plan, small area plan, project/corridor) and the three geographic regions of North Carolina would be represented (eastern, piedmont, and western). Additionally, we only selected projects for which the results of the HIA could help inform a future decision, such as the allocation of funding for project construction. Based on these criteria, we selected the Blue Ridge Road project in Raleigh, NC; projects from the Greenville Metropolitan Planning Organization (MPO) Bicycle and Pedestrian Master Plan in Winterville, NC; and the second phase of the Downtown Streetscape Strategy in Sparta, NC (see Table 1).

The Health Advisory Team also discussed potential modeling tools that could be applied to conduct a quantitative HIA. Three models were considered: the Health Economic Assessment Tool (HEAT) for Walking and Cycling, developed by the World Health Organization,[6] the Dynamic Modeling for HIA (DYNAMO-HIA) model, developed by the National Institute for Public Health and the Environment in the Netherlands,[7] and the Prevention Impacts Simulation Model (PRISM), developed with the support of the Centers for Disease Control and Prevention (CDC).[8] After discussing the advantages and disadvantages of each modeling tool, we selected the DYNAMO-HIA model due in large part to the power and flexibility of the modeling framework, which are described in detail in the Methods section. Table 2 compares the advantages and disadvantages of these three modeling tools.

Table 1. HIA Demonstration Projects

Planning Scale	Development Context: Rural	Development Context: Suburban	Development Context: Urban
Corridor	Sparta Downtown Streetscape Strategy		
Small Area			Blue Ridge Road Neighborhood (Raleigh)
Comprehensive		Greenville Bicycle and Pedestrian Master Plan (Winterville)	

Geographic Context:
- Eastern North Carolina (blue)
- Piedmont (orange)
- Western North Carolina (green)

Table 2. Comparison of HIA Tools

Model	Advantages	Disadvantages
HEAT	• *Minimal data needs* • *Epidemiological evidence built-in* • *User-friendly*	• *Stationary* • *Rigid model structure*
DYNAMO-HIA	• *Dynamic* • *Flexible* • *Modular*	• *Significant data needs* • *Requires disease prevalence & incidence* • *Epidemiological evidence not built-in* • *Difficult to use*
PRISM	• *Dynamic* • *Minimal data needs* • *Epidemiological evidence built-in* • *User-friendly*	• *Model structure not customizable* • *Cannot specify new risk factors or interventions not included in base model* • *Difficult to focus specifically on built environment interventions*

Greenville MPO Bicycle and Pedestrian Master Plan, Winterville, NC

Winterville is a suburban community located just south of Greenville, NC. In 2011, the Greenville MPO completed a Bicycle and Pedestrian Master Plan for the Greenville Metropolitan Area, which includes Winterville. We conducted an HIA on the complete build-out of the pedestrian elements of the plan in Winterville compared to the baseline, status quo scenario. The plan includes the construction of new sidewalks as well as the construction of bicycle facilities, which are not assessed (Figure 1). This project is in the suburban context, at the comprehensive plan scale, and in the eastern portion of the state.

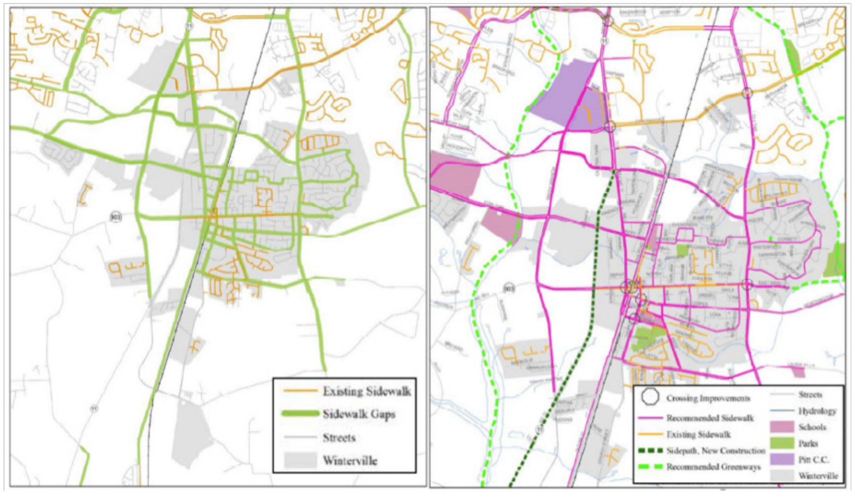

Figure 1. Winterville existing pedestrian facilities (left) and proposed improvements (right)

Blue Ridge Road Project, Raleigh, NC

Situated just outside the beltline in Raleigh, NC, the Blue Ridge Road project is the result of an ambitious community visioning and planning effort. Blue Ridge Road is a key transportation link in a small-area plan that envisions an urban future for the Blue Ridge corridor. We conducted an HIA comparing the built-out vision of Blue Ridge Road as envisioned in the small-area plan to the status quo scenario (i.e., current conditions). The small area plan includes significant land-use change, construction of new sidewalks, and streetscape improvements (Figure 2). The BRRC project is classified as an urban project at the small-area plan scale in the Piedmont region of North Carolina.

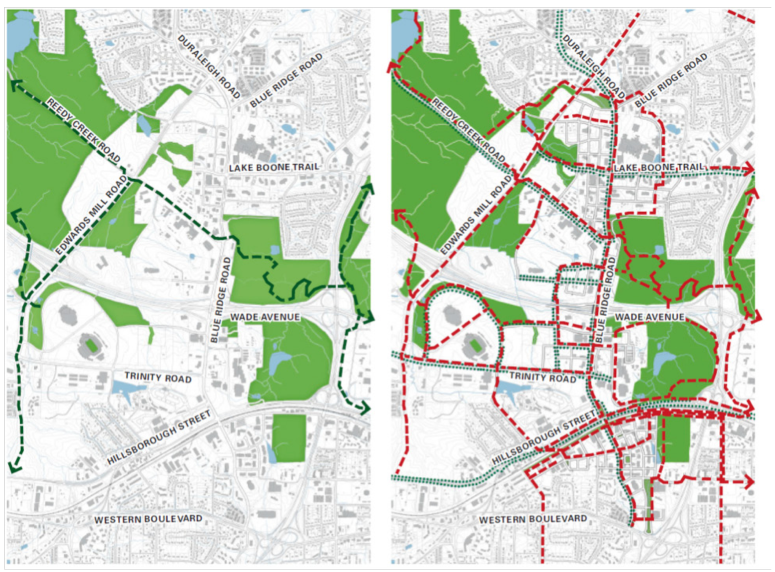

Figure 2. BRRC existing open space and trails (left) and proposed open space, trails, and improved sidewalks (right)

Downtown Streetscape Master Plan, Sparta, NC

Sparta, NC, is a traditional "main street community" located in western North Carolina. The town of Sparta recently completed a Downtown Streetscape Strategy in 2012, including significant pedestrian improvements to downtown. We conducted an HIA on the implementation of the plan and compared the results to the status quo scenario. The project contains streetscape and street crossing improvements along Main Street, which runs through downtown Sparta, as well as complementary improvements to several side streets (Figure 3). This project is in the rural context, at the corridor scale, and is located in western North Carolina.

Figure 3. Sparta proposed downtown streetscape improvements

Our three demonstration HIAs share a common decision point: the implementation of one or more projects as articulated in a planning document. Thus, the results of our HIAs may be used to inform project prioritization processes at the local and state levels. We intend for the results of our HIAs to be used by local decision makers in each community – not only do we demonstrate quantitative methods in conducting HIAs, but we also demonstrate how quantitative health impacts may help inform decision-making processes and enable the consideration of the health impacts in allocating funds for transportation infrastructure in the state of North Carolina. While we selected three demonstration projects to demonstrate the value and validity of quantitative HIA methods across different contexts, caution should be exercised in generalizing the findings of this HIA to other cities and towns in North Carolina.

Scoping

We divided the scoping phase into two primary stages: 1) meetings with local decision-makers in each community to identify existing health concerns and barriers to active transportation behaviors; and 2) screening and selection of appropriate diseases for inclusion in our model.

Community Meeting Summary: Winterville

On December 10th, 2012, we hosted a project meeting in the Town of Winterville offices to identify health disparities and local contextual factors. Three common themes emerged: 1) Underlying socio-demographic characteristics and cultural norms that influence health outcomes; 2) inadequacies in physical infrastructure that present barriers to active transportation; and 3) land use patterns that present barriers to active transportation. The importance of correctly framing active transportation as a normative rather than elitist behavior was also mentioned several times – that is, the perception of cycling as an elite activity may be a barrier for new cyclists whereas the perception of walking as the opposite may also be a barrier. Key health barriers organized by broad topic areas are summarized in Table 3; a full meeting summary and list of participants is provided in Appendix 2 of this report.

Table 3. Winterville Community Meeting Key Issues

Issue Area	Identified Barriers
Built Environment and Land Use	• Non-walkable development scales • Car-oriented development • Segregated land uses • Lack of services and employment within Winterville proper • School siting
Transportation Infrastructure	• Lack of sidewalks • Poor sidewalk connectivity between developments • Road widening projects undertaken without supplementary improvements such as the addition of sidewalks and bike lanes • Barriers presented by the highway and rail line that bisect Winterville • Aesthetic quality of many streetscapes, including NC 11
Demographic and Cultural Factors	• High rates of poverty • High prevalence of risk factors (smoking, alcohol consumption, etc.)
Services	• Lack of public transit service • Poor access to facilities that offer affordable healthcare
Social and/ or economic conditions	• Stigmatized perception of walking and biking for transportation • Poor awareness of the rules of the road by drivers, cyclists, and pedestrians in multi-modal situations
Natural Environment	• Noise and air pollution due to NC Highway 11

Focusing specifically on physical inactivity, participants noted that lack of physical activity is a risk factor for a range of health outcomes including overweight/obesity, heart disease, and mental health. Specific populations susceptible to physical inactivity were identified primarily based on geography rather than socio-demographic characteristics; that is, the workshop participants felt that neighborhood quality was more important than individual characteristics in explaining the propensity to use physically active transportation modes.

Community Meeting Summary: Sparta

On December 18th, 2012, we hosted a project meeting in the Sparta Town Hall to identify health concerns in the community. Three central themes emerged during our discussions: 1) barriers to active transportation related to poor pedestrian safety (both real and perceived); 2) inadequacies in physical infrastructure that present barriers to active transportation; and 3) health disparities associated with high prevalence of poverty and a high number of seasonal workers. Participants also suggested framing active transportation as an issue of personal choice: expanding infrastructure that is supportive of active transportation expands personal choice and gives individuals new opportunities to choose to be active as part of their daily routine. Key issues are summarized in Table 4; a full summary and list of participants is provided in Appendix 2 of this report.

Table 4. Sparta Community Meeting Key Issues

Issue Area	Identified Barriers
Built Environment and Land Use	• Incomplete sidewalk network • Heavy traffic along key routes • Segregated land uses • Rural school siting
Transportation Infrastructure	• Lack of sidewalks • Width and quality of existing sidewalks (e.g., electric poles in the middle of sidewalks) • Lack of passing zones (to pass cyclists) on rural roads • Wide lanes throughout Sparta that encourage high travel speeds • Downtown aesthetics not conducive to walking
Demographic and Cultural Factors	• High rates of poverty • Older population • High proportion of population without health insurance • Cultural bias towards the car due in part to Sparta's rural setting • Poor nutrition/access to healthy foods • Cultural norms that support tobacco use
Services	• Lack of public transit service • Fragmentation of government services downtown - services were historically housed in a single building and residents would park once in downtown and walk to other destinations; now services are offered in different buildings and residents are more likely to drive to each building
Social and/ or economic conditions	• Stigmatization of walking for transportation • Large percentage of the population on fixed incomes • Large number of seasonal workers
Natural Environment	• Extreme elevation changes in the community make cycling very difficult; largely a recreational activity • Lack of programmed open space (e.g., sports fields, playgrounds, etc.)

Focusing specifically on physical inactivity as a determinant of health, participants identified the lack of safe opportunities to cross the street, high traffic speed, and traffic signaling that is unsafe for pedestrians (e.g., right turn green arrows and protected right turn lanes) as primary barriers to increased walking due to negative effects (real and perceived) on pedestrian safety. Participants also identified several sub-populations that may be impacted by targeted improvements, including students who are unable to walk to school due to gaps in the sidewalk network, seasonal workers who do not have a car and must walk to work since there is no public transit, and carless households that also must rely on walking as a primary mode of transportation.

Scoping Summary: Blue Ridge Road Corridor (BRRC)

Five facilitated focus group interviews were previously completed for the BRRC to gather public input regarding health disparities in the community.[12] Specifically, the focus groups were structured around on three general topics:

1. What elements of the BRRC neighborhood and environment, as it currently exists, do stakeholders identify as a concern to public health?
2. What health effects, both positive and negative, can be identified in the BRRC that might be affected through planning, design, and change to infrastructure?
3. How can existing plans or conceptual designs for the BRRC address specific health concerns?

Key issues raised by stakeholders in focus group discussions are summarized in Table 5. Major themes that emerged during focus group discussions included the lack of sidewalks and crosswalks posing a threat to public health, the perception of the BRRC as a dangerous place due to the threat of injury, the lack of convenient public transit, the environment of BRRC being stressful, and the large gaps that exist between destinations along the corridor limiting pedestrian and bicycle travel. Stakeholders specifically defined stress and safety from injury as an important public health impact related to the current design of the BRRC. Focus group discussions were structured to also give participants an opportunity to identify preferred design changes for addressing health concerns in the BRRC. The top seven design changes for the corridor were: 1) Make BRRC more aesthetically pleasing; 2) Ensure that sidewalks and crosswalks are built on the majority of roads; 3) Build more things to walk to (e.g., coffee shops, restaurants, etc.); 4) Build bike lanes and install bike racks; 5) Improve connections to and between modes of public transit; 6) Provide educational opportunities; and 7) Improve publicity (e.g., better mapping, signage, etc.) A number of these design interventions are linked directly to walkability – and active transportation infrastructure is addressed as a specific design intervention for improving public health in the BRRC area.

Table 5. BRRC Focus Groups Key Issues

Issue Area	Identified Barriers
Built Environment and Land Use	• *Lack of adequate sidewalks in the BRRC area* • *Lack of adequate crosswalks in the BRRC area* • *Large gaps between pedestrian destinations*
Transportation Infrastructure	• *Lack of adequate sidewalks in the BRRC area* • *Lack of adequate crosswalks in the BRRC area* • *Intersections and roads designed primarily for private automobiles* • *Lack of an efficient roadway network* • *Lack of clear trail indicators (e.g., wayfinding signs, maps, etc.)* • *Not all pedestrian facilities open at night*
Demographic and Cultural Factors	• *Presence of drunk/distracted drivers*
Services	• *Lack of public transit service* • *Poor connections to and in between public transit services*
Social and/ or economic conditions	• *No barriers identified*
Natural Environment	• *No barriers identified*

Assessment: Methods

We use the DYNAMO-HIA model to estimate the health impacts of active transportation improvements in the three study areas. DYNAMO-HIA is a powerful, flexible, and dynamic health impacts modeling tool developed by the National Institute for Public Health and the Environment in the Netherlands. To our knowledge, DYNAMO-HIA has not been used in the United States nor has it been applied to a transportation infrastructure project to date; thus, our analysis offers an innovative and unique approach to estimating the health outcomes of active transportation infrastructure. The DYNAMO-HIA modeling framework enables users to combine epidemiological evidence, public health and demographic data, and transportation behavior information to predict age- and sex-specific health outcomes over time. This state of the art model is a significant methodological advancement compared to common HIA practice in the United States today. Specifically, DYNAMO-HIA uses a Markov Chain modeling approach in which the population is divided into a number of baseline health states at the beginning of the simulation and transitions between health states (healthy, diseased, or deceased) are modeled as the population ages through time. Transitions between states are characterized by epidemiological evidence, baseline disease data, and risk factor exposures. The model moves forward through time in 1-year time increments, maintaining population data between time periods. In a sense, the model divides the population into 95 male and 95 female one-year age cohorts and tracks each cohort through time. Previous applications of the DYNAMO-HIA model have predicted the health impacts of smoking cessation in Great Britain and changes in alcohol consumption in Sweden.[13] Outside of the health sector, Markov Chain approaches have been applied to model a wide range of phenomena, stock prices, asset price volatility, and political transitions from authoritarian to democratic regimes.[14-16] Thus, while our modeling approach is unique, a significant body of work exists documenting the ability of Markov Chain approaches to model conceptually similar dynamic processes in the public health field and in other sectors.

Model Development

DYNAMO-HIA provides a great deal of flexibility to the user. While the model contains a predefined structure, the user is free to add layers of detail to the model in a modular fashion. In particular, the user is free to select any number of diseases they wish to include in the model and to select and characterize a single risk factor. We base our DYNAMO-HIA model on a conceptual model in which active transportation infrastructure increases active transportation behavior, and thereby increases physical activity levels in the population, which in turn has an effect on the prevalence of disease and mortality from all causes. This conceptual model is supported by research in transportation behavior that establishes a relationship between built environment characteristics and active transportation behavior and research indicating that physical activity, even at low to moderate intensity and for relatively short durations, has significant implications for a wide range of diseases as well as for all-cause mortality.[17-21] Thus, we selected physical inactivity as the risk factor in our model.

In selecting diseases to include in our model, we reviewed epidemiological evidence to ensure that included diseases are linked to walking for transportation. While recent research has established connections between a wide range of diseases and physical activity, the intensity of physical activity plays a critical role in characterizing this relationship for certain health outcomes. For certain diseases, both moderate and vigorous physical activity reduce disease risk; however, epidemiological studies suggest that the risk of some diseases is attenuated only by vigorous physical activity. Given the typically moderate physical activity levels accrued during active transportation, we focused our attention on diseases with a proven epidemiological link to moderate physical activity.[22] Initially, this process resulted in the identification of seven diseases: 1) Breast Cancer; 2) Chronic Pulmonary Obstructive Disorder (COPD); 3) Colon Cancer; 4) Coronary Heart Disease (CHD); 5) Diabetes; 6) Hypertension; and 7) Stroke. However, this initial list required further screening prior to inclusion in the DYNAMO-HIA model. Diseases were first screened based on the availability of baseline prevalence data at an appropriate geographic scale (the county, if available, or multi-county regions if county data were unavailable) and subsequently screened based on peer-reviewed epidemiological studies linking moderate transportation physical activity to disease risk. After this multi-stage screening process, four diseases were selected for final inclusion in the DYNAMO-HIA model: 1) CHD; 2) Diabetes; 3) Hypertension; and 4) Stroke. Breast and Colon Cancer were not included due to data limitations at the county level while COPD was not included due to a lack of epidemiological studies linking transportation-derived physical activity to health outcomes. The combination of these diseases address many stakeholder concerns identified during the Scoping phase. However, we were unable to consider obesity explicitly in our model due to a lack of detailed epidemiological evidence linking non-vigorous and transportation physical activity to obesity outcomes.

The final choice left in constructing our DYNAMO-HIA model was the characterization of the physical activity risk factor. A comprehensive review of epidemiological studies was used to determine the strength of the relationship between non-vigorous physical activity and health outcomes as well as the manner in which non-vigorous physical activity was measured. Epidemiological studies link physical activity to various health outcomes using relative risks (RR), which is the risk of developing a certain health outcome when exposed to a risk factor divided by the risk of developing the same health outcome when not exposed to the risk factor. Mathematically, a relative risk is defined as:

$$RR = \frac{p_{event\ when\ exposed}}{p_{event\ when\ not\ exposed}}$$

In the context of physical activity, increasing levels of walking for transportation reduces the risk of negative health outcomes. Thus, RR values are less than 1 and lower RR values represent a more powerful relationship between transportation physical activity and the health outcome. Values for RR are typically defined at different levels of transportation physical activity; thus, RR is a function of the level of physical activity as well as the specific health outcome. Disease-specific studies consider physical activity from transportation as a distinct independent variable and classify activity using the same categories (0 minutes per week; 1-149 minutes per week, or 150 or more minutes per week) and provide relative risks for males and females.[18-20] Thus, we characterize the physical activity risk factor as a categorical variable with the same categories as are used in the epidemiological studies reviewed. For all-cause mortality, a recent meta-analysis was identified that provides a continuous dose-response model for transportation physical activity.[21] From these data, we derived RR values for all-cause mortality for each defined risk factor class by calculating the RR value at the mid-point of the middle category (75 minutes per week) and the low point of the higher category (150 minutes per week). These data are not disaggregated by sex. When studies provided several models controlling for various confounding variables, we select the least adjusted RR values because our model does not address typical confounders such as smoking and education. These data are summarized in Table 6 and our final DYNAMO-HIA model is presented schematically in Figure 4.

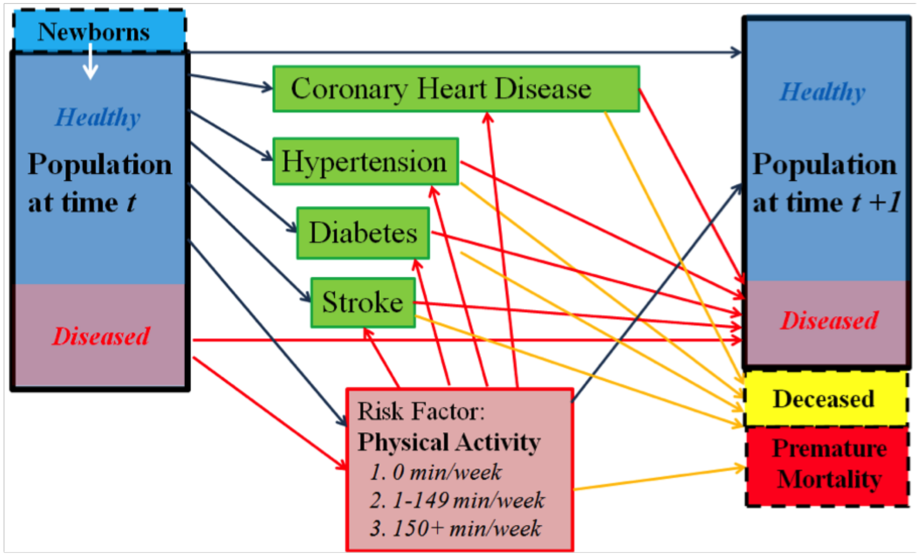

Figure 4. Model Schematic, representing simulation of one time step

Table 6. Summary of Epidemiological Studies Used to Relate Physical Activity to Health Risk

Disease	Study	Sex	Relative Risk of Health Outcome			Model Controls
			No PA	1-149 min/wk	150+ min/wk	
CHD	Hu et al. 2007	Male	1	**0.88**	**0.80**	Age, study year
		Female	1	**0.89**	**0.64**	
Diabetes	Furie and Desai 2012	Combined	1	**0.77**	**0.69**	Race, education, income, smoking
Hypertension	Furie and Desai 2012	Combined	1	**0.76**	**0.69**	Race, education, income, smoking
Stroke	Hu et al. 2005	Male	1	**0.86**	**0.82**	Age, study year
		Female	1	**0.83**	**0.80**	
Mortality, all-cause	Woodcock et al. 2010	Combined	1	**0.926**	**0.898**	n/a; meta-analysis

RRs for each risk factor category reported for all-cause mortality relative to reference category

Baseline Data: Population

We collected baseline demographic and health data for each study area from the North Carolina State Center for Health Statistics (NCSCHS). All data were collected for the year 2009 because the 2009 Behavioral Risk Factor Surveillance System (BRFSS) survey contained an additional question regarding active transportation behavior in 2009. Population data, stratified by age and sex at the county level, were taken from NCSCHS population estimates.[23] The age distribution of these data within census age groups were then applied to 2009 census data for specific block groups for each study area to refine these data and provide age- and sex-specific populations for each study area. To estimate newborns, the 2009 county birthrate and male to female ratio, both taken from the NCSCHS Vital Statistics records, was assumed to remain constant throughout the study period.[24] Newborns for each year were estimated to equal population size times the birthrate, growing the base population yearly by the natural population growth rate, also reported in the NCSCHS Vital Statistics data. This process is documented in greater detail in Appendix 3 of this report.

Baseline Data: Disease Prevalence

We use a method similar to the one applied to population data to refine disease prevalence into smaller age categories. Four questions from the 2009 BRFSS survey, each corresponding to a different disease, were used to develop population disease prevalence estimates.[25] Questions and corresponding disease are listed in Table 7. In the 2009 BRFSS public data, county-level data for all diseases are reported split into two age groups (18-44 and 45+) whereas regional data are reported split into six age groups (18-24, 25-34, 35-44, 45-54, 55-64 and 65+). We assume that the observed distribution for the five-age group data at the regional level underlies the reported two-age group data at the county level. Thus, we use the five-age range distribution to estimate county-level disease prevalence in the same five age groups by adjusting regional-level values using county-level population estimates and observed prevalence values. We then estimate age-specific prevalence functions for each disease using a fitted second-order numerical function. We then use these continuous disease prevalence functions to estimate prevalence for each 1-year age group used in DYNAMO-HIA (i.e., 1, 2, 3, etc.) This process is described in Appendix 3 of this report.

Table 7. 2009 BRFSS Survey Questions Used

Question	Wording	Data
9.2[a]	*Has a doctor, nurse, or other health professional ever told you that you had angina or coronary heart disease?*	*CHD Prevalence*
6.1[a]	*Have you ever been told by a doctor that you have diabetes?*	*Diabetes Prevalence*
7.1[a]	*Have you ever been told by a doctor, nurse, or other health professional that you have high blood pressure?*	*Hypertension Prevalence*
9.3[a]	*Has a doctor, nurse, or other health professional ever told you that you had a stroke?*	*Stroke Prevalence*
16.1[b]	*In the past week, how much time did you walk or bicycle for transportation, such as to and from work or shopping?*	*Baseline PA from Transportation*

[a]CDC core section question   [b]North Carolina added question

Baseline Data: Disease Incidence

The 2009 BRFSS survey data report disease prevalence – the percentage of the population with a given disease at a given time – but do not report disease incidence – the rate of new disease cases in the population over time.[5] However, the DYNAMO-HIA model requires both prevalence and incidence for each disease included. We estimate disease incidence using a method developed by Ralph Brinks, a researcher at Institute for Biometry and Epidemiology in Düsseldorf, Germany.[26] Conceptually, we use age-specific prevalence data, combined with age-specific mortality estimates for individuals with and without the disease, to estimate the rate at which individuals of different ages must develop the disease for the prevalence data to be realized as observed in the 2009 BRFSS survey. This method is described in Appendix 3.

Baseline Data: Walking for Transportation

For the Winterville and Sparta study areas, we obtained baseline active transportation behavior from the 2009 BRFSS, in which the state of North Carolina included a supplementary question regarding active transportation. These data are available at the county level; however, they are not stratified by gender or age. Thus, we assume that active transportation behavior prevalence is constant across all ages and for both genders. For the Blue Ridge Road study area, we used a survey conducted in 2010 based on the International Physical Activity Questionnaire (IPAQ), a validated survey that has been used in a wide range of physical activity studies.[12,27] For both active transportation behavior data sources, we assume that the distribution of minutes of activity per week is constantly distributed within each time category in each survey and that half of all BRFSS respondents who report more than 2 hours of active transportation per week are engaged in active transportation less than 2.5 hours per week and half are engaged in active transportation more than 2.5 hours per week. We use these data to estimate the prevalence of each risk factor category (0 minutes per week, 1-149 minutes per week, or more than 150 minutes per week) in our model.

Baseline Data: Winterville

Baseline data for the Winterville study area are summarized below. Figure 5 shows the 2009 population distribution by age and sex. In total, the study area has a population of 9,269 residents, of which 4,944 are female and 4,320 are male. The study area contains a relatively large number of residents above age 30; however, there are relatively few residents in the 15-30 age range.

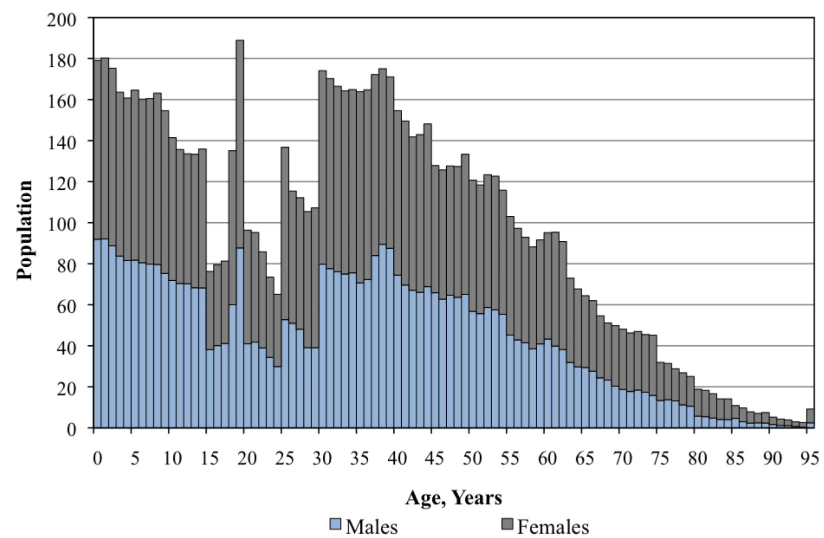

Figure 5. Winterville 2009 Population Distribution by Age

Baseline disease prevalence and estimated incidence by age for CHD, Diabetes, Hypertension, and Stroke for the Winterville study area are summarized in Figure 6. Observed prevalence data are plotted with black crosses and a fitted age-specific prevalence function is plotted with a solid black line. Estimated incidence data are plotted with red crosses and a fitted red line. Data are shown for ages 18-75 only.

Baseline active transportation behavior for the Winterville study area, taken from the 2009 BRFSS survey is presented in Table 8, in both raw form and aggregated based on our physical activity risk factor classifications.

Table 8. Baseline Walking for Transportation, Winterville

2009 BRFSS Survey Results		Grouped Based on Risk Factor Categories	
Min. Transportation PA per Week	Percentage of Population	Min. Transportation PA per Week	Percentage of Population
0	84.3%	0	84.3%
1-29	3.4%	1-149	12.3%
30-59	2.5%	1-149	12.3%
60-119	2.9%	1-149	12.3%
120+	6.9%	150+	3.4%

9.4

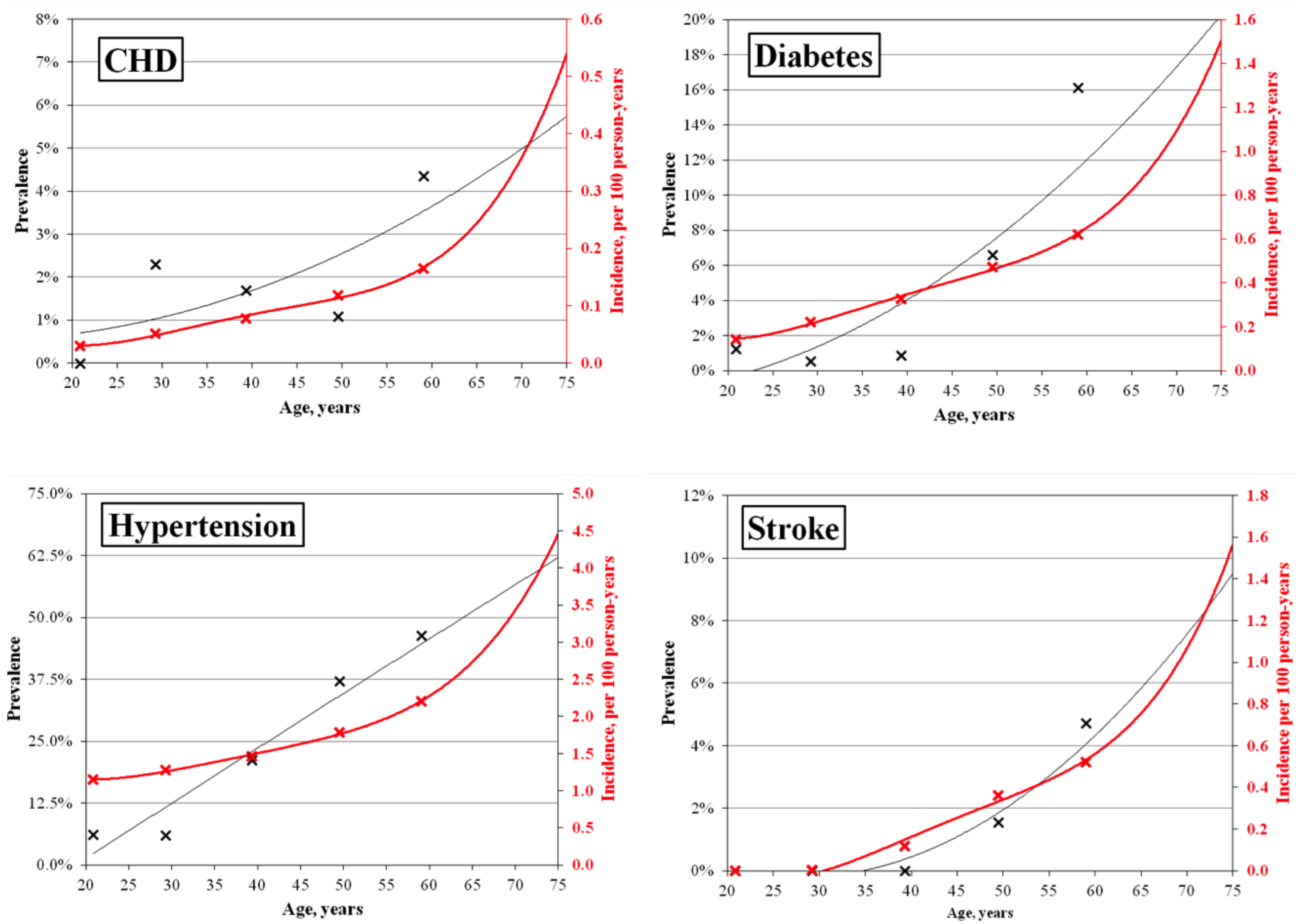

Figure 6. Winterville 2009 Disease Prevalence and Incidence, by Age

Baseline Data: Blue Ridge Road

Baseline data for the BRRC study area are summarized below. Figure 7 shows the 2009 population distribution by age and sex. In sum, the study area contains 10,929 residents, of which 6,056 are female and 4,873 are male. The study area contains a relatively large number of residents between the ages of 18 and 24, especially females in this age group, partially due to its proximity to Meredith College. Baseline disease prevalence and estimated incidence by age for CHD, Diabetes, Hypertension, and Stroke for the BRRC study area are summarized in Figure 8.

Baseline active transportation behavior for the BRRC study area is summarized Table 9, in both raw form and aggregated based on our physical activity risk factor classifications.[12]

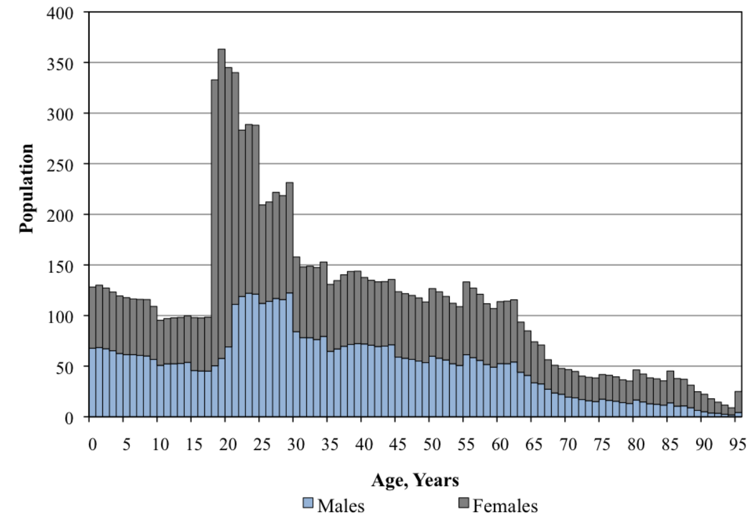

Figure 7. BRRC 2009 Population Distribution by Age

Table 9. Baseline Walking for Transportation, BRRC

BRRC Survey Results		Grouped Based on Risk Factor Categories	
Min. Transportation PA per Week	Percentage of Population	Min. Transportation PA per Week	Percentage of Population
0	40.7%	0	40.7%
1-60	23.3%	1-149	40.8%
61-120	14.5%	1-149	40.8%
121-140	2.1%	1-149	40.8%
141-160	1.8%	1-149	40.8%
161+	17.6%	150+	18.5%

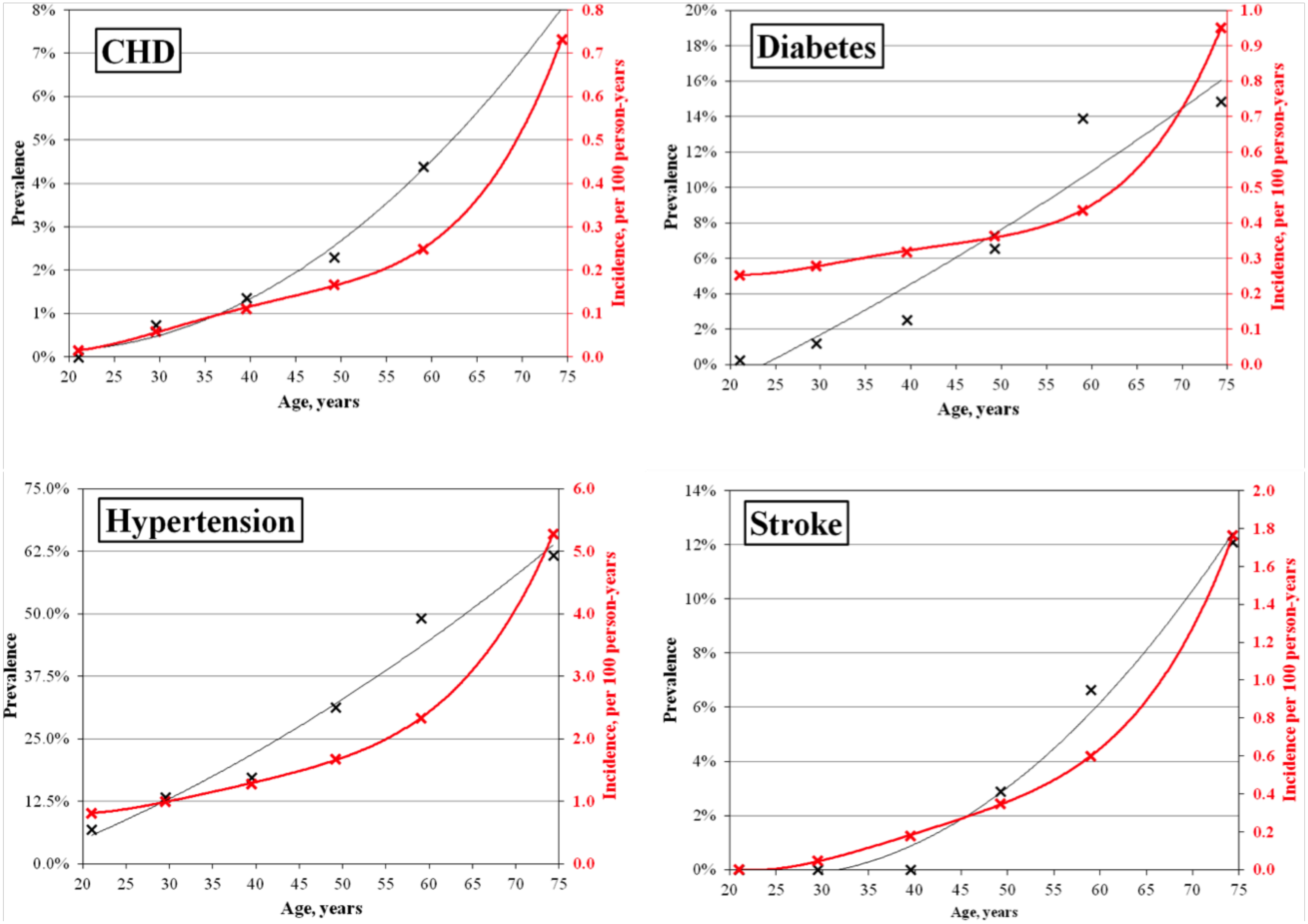

Figure 8. BRRC 2009 Disease Prevalence and Incidence, by Age

Baseline Data: Sparta

Baseline data for the Sparta study area are summarized below. Figure 9 shows the 2009 population distribution by age and sex. The study area contains a total of 1,770 residents. The study area contains a more equal distribution of males to females than Winterville and the BRRC, with 882 female residents and 888 male residents. Sparta is also relatively older than both other study areas, with population distributed fairly evenly up to 75 years of age. Baseline disease prevalence and estimated incidence by age for CHD, Diabetes, Hypertension, and Stroke for the Sparta study area are summarized in Figure 10.

Baseline active transportation behavior for the Sparta study area, taken from the 2009 BRFSS survey is presented in Table 10, in both raw form and aggregated based on our physical activity risk factor classifications.

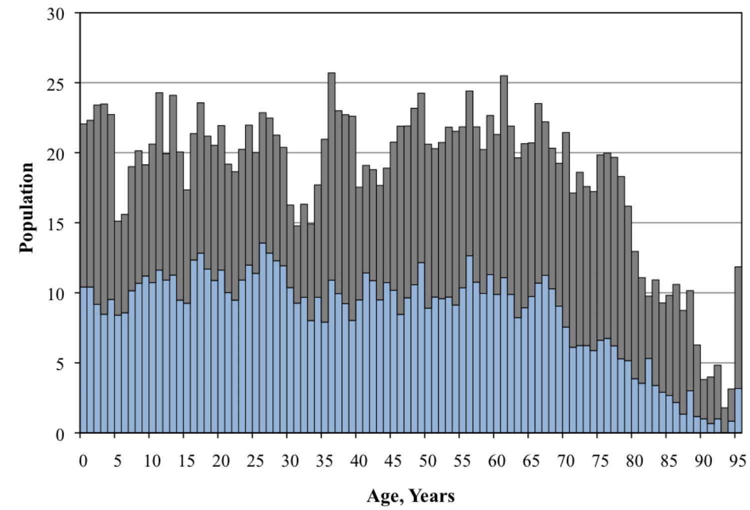

Figure 9. Sparta 2009 Population Distribution by Age

Table 10. Baseline Walking for Transportation, Sparta

2009 BRFSS Survey Results		Grouped Based on Risk Factor Categories	
Min. Transportation PA per Week	Percentage of Population	Min. Transportation PA per Week	Percentage of Population
0	83.8%	0	83.8%
1-29	4.4%	1-149	13.5%
30-59	3.3%	1-149	13.5%
60-119	3.0%	1-149	13.5%
120+	5.5%	150+	2.8%

9.4

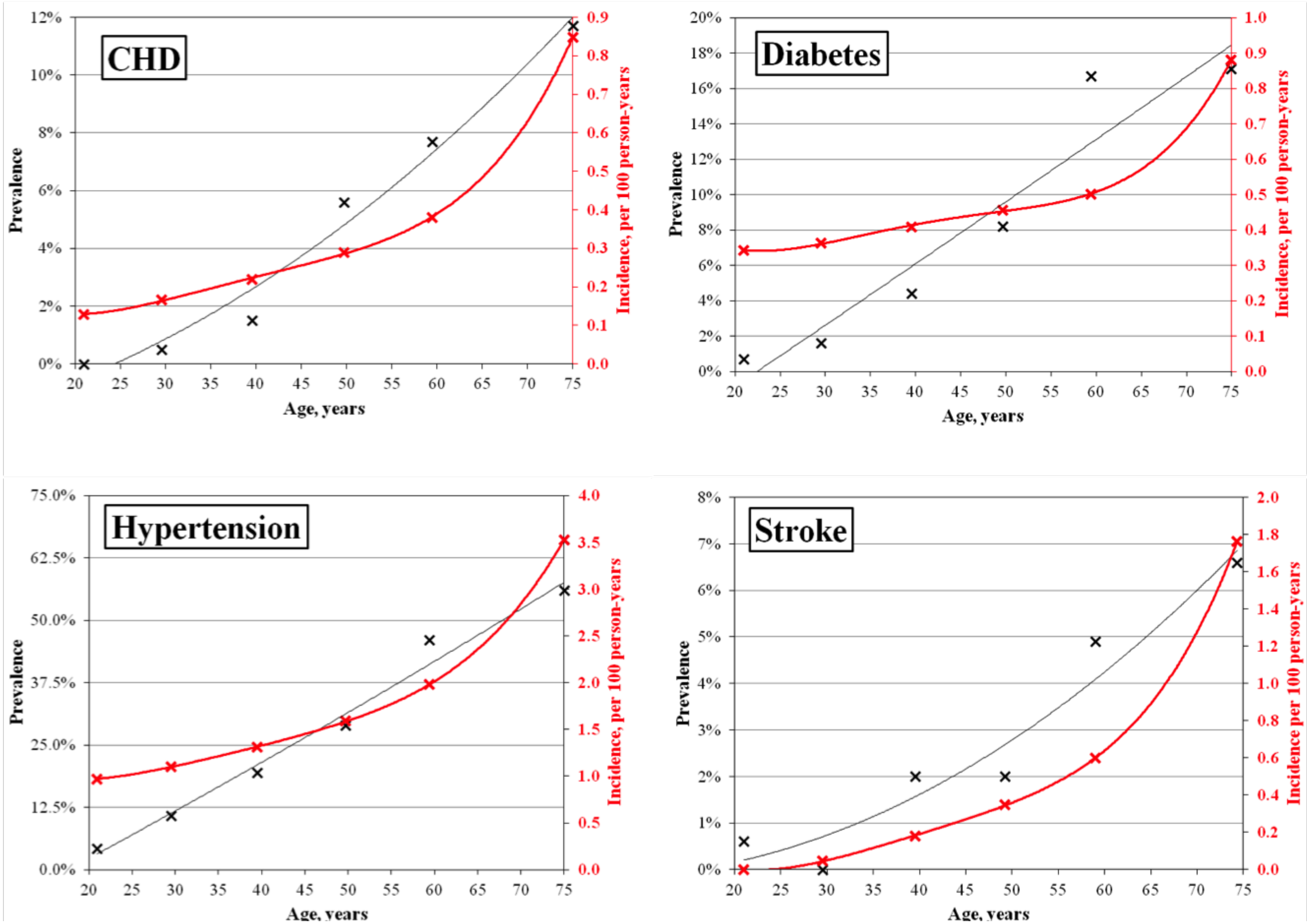

Figure 10. Sparta 2009 Disease Prevalence and Incidence, by Age

Assessment: Results

We constructed separate models to estimate the health impacts of active transportation infrastructure improvements in each community. In each model, we considered five health outcomes, disaggregated by gender: 1) avoided all-cause mortality; 2) avoided cases of CHD; 3) avoided bases of diabetes; 4) avoided cases of hypertension; and 5) avoided cases of stroke. Each model compares two scenarios, a baseline scenario and an intervention scenario, through time. We assumed that active transportation behavior would stay constant in the baseline scenario and would increase due to changes in the built environment in the intervention scenario. Thus, the health impacts of changes in the built environment are captured by the differences in health estimated outcomes over time between the two scenarios. We ran each model for 50 years, starting in 2009. The starting date of the simulation is somewhat arbitrary. We used 2009 because data for walking for transportation are only available in the 2009 BRFSS; however, we interpreted model outputs in terms of "years from the present," assuming that in some future year the project will be implemented and health impacts will grow through time from that future date.

The baseline and intervention scenarios are identical aside from one aspect: the percentage of the population in each risk factor category. Differences in health status between the two scenarios emerge through time as the population ages, distributed differently into higher and lower risk groups. All cohorts in the intervention scenario born in 2009 and thereafter spend all of their lives with a greater chance of being in a lower risk group due to increased physical activity from active transportation while population cohorts born prior to 2009 spend relatively smaller percentages of their lives with a greater chance of being in a lower risk group. Therefore, younger populations and those born in 2009 and later have a greater chance of being at reduced risk for adverse health outcomes throughout their lives due to the built environment interventions considered. Thus, improved health outcomes in the intervention scenario become more pronounced over time as individuals spend a greater portion of their total lives in lower risk factor categories resulting from transportation physical activity.

Intervention Data: Walking for Transportation

For each study area, we calculate pre- and post-project built environment variables and use these data to estimate changes in active transportation behavior in the community. For Winterville and the BRRC, we focus on the construction of new sidewalks and greenways while in Sparta we consider improvements to existing sidewalks. We calculate pre- and post-project sidewalk length, measured in miles, and sidewalk density, measured in miles of sidewalk per square mile of land. Sidewalks on two sides of the same street are both counted (i.e., a one mile length of road with sidewalks on both sides is considered two miles of sidewalks) and greenways are included in sidewalk length totals. We translate pre- and post-project built environment to estimate changes in physical activity from transportation using behavioral evidence in three ways: 1) increased average walking time due to increases in the extent of the sidewalk network; 2) increased odds of making a walking trip due to increases in the density of the sidewalk network; and 3) increased per capita walking distance in neighborhoods with a higher Pedestrian

Environment Factor (PEF). While the travel behavior literature is generally consistent in its findings,[17] it is difficult to generalize findings across cities and regions; however, we used methods consistent with the best evidence in the literature today. Methods are described in greater detail in Appendix 3.

Previous research conducted using built environment variables and travel survey data in the Raleigh-Durham-Chapel Hill Metropolitan Statistical Area found that a 1% increase in total sidewalk network length results in a 0.12% increase in average walking time per person. Additionally, every additional mile of sidewalk per square mile increases the odds of an individual having taken a walking trip by 1.4%.[17,28] Thus, we use total sidewalk length to estimate the increased walking time for existing walkers and sidewalk density to estimate the number of new walkers. The time spent walking by new walkers is assumed to be distributed in a similar manner as for existing walkers and new walkers are added to each category appropriately. For Sparta, we consider improvements to the quality of the pedestrian environment using the PEF developed in Portland, Oregon.[29-30] We estimate the pre- and post- PEF for the downtown area, considering sidewalk quality, ease of street crossings, topography, and local street network configuration. We assume that a transition from the lowest third of PEF to the middle third of PEF results in an average increase of 0.71 miles walked per person per week and from the lowest third to the highest results in an increase of 1.32 miles walked per person per week.[30] We assume a conservative average walking speed of 2.5 miles per hour to convert to time.[31]

Intervention Data: Winterville

Pre- and post-project built environment variables of interest, as well as predicted effects on walking behavior consistent with the behavioral literature reviewed, are presented in Table 11. Implementing all projects included in the Pitt County Pedestrian and Bicycle Master Plan, as well as other currently proposed sidewalks, would increase the length of sidewalk in Winterville from 14.3 to 65.7 miles. This results in an increased walking time amongst existing walkers of 43.2%. These new sidewalks would also increase sidewalk coverage, measured in sidewalk density, from 1.3 miles of sidewalk per square mile of land area to 4.8 miles of sidewalk per square mile of land area. This results in an increase in the odds of someone taking a walking trip during the week by 6.8%, meaning that some individuals who do not walk for transportation before the construction of the sidewalks will do so after the construction of the sidewalks.

Table 11. Pre- and Post-project Built Environment Variables, Winterville

	Pre-project	Post-project	Change	Behavioral Response
Sidewalk Length	*14.3 mi*	*65.7 mi*	*+360%*	*Increase in average walking time:* ***43.2%***
Sidewalk Density	*1.3 mi/mi²*	*6.1 mi/mi²*	*+4.8 mi/mi²*	*Increase in odds of taking a walk trip:* ***6.8%***

Health

Predicted active transportation behavior after the proposed built environment change, as well as the difference relative to the baseline, are presented in Table 12. A small shift from the non-walking category into a walking category is predicted. Additionally, a larger shift from the lower walking category to the upper walking category is predicted, with a large increase in the percentage of the population walking greater than 150 minutes per week and a related decline in the percentage of the population walking less than 150 minutes.

Based on these predicted changes in physical activity from walking for transportation, we predict significant positive health impacts. Fifty years after the construction of the project, 2 lives will be saved, and a modest percentage of future cases of each disease considered will be avoided. Modeled health impacts through time for both genders are shown in Figure 11, with lives saved plotted on the left axis and percentage of disease cases avoided on the right axis. These results are disaggregated by gender and displayed in Table 18 with numbers of disease cases rather than percentage of disease cases avoided to ease comparisons across projects for three time periods.

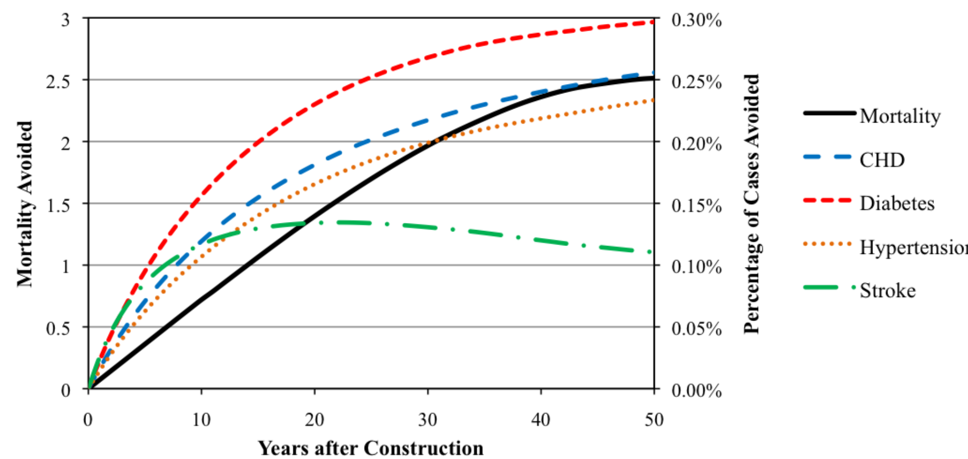

Figure 11. Winterville Predicted Health Outcomes

Table 12. Post-Intervention Walking for Transportation, Winterville

Estimated Intervention Active Transportation Behavior		Grouped Based on Risk Factor Categories		
Min. Transportation PA per Week	Percentage of Population	Min. Transportation PA per Week	Percentage of Population	Change, Relative to Baseline
0	83.4%	0	83.4%	**-0.9%**
1-29	3.6%	1-149	10.9%	**-1.4%**
30-59	2.6%	1-149	10.9%	**-1.4%**
60-119	3.1%	1-149	10.9%	**-1.4%**
120+	7.3%	150+	5.7%	**+2.3%**

9.4

Intervention Data: BRRC

Pre- and post-project built environment variables of interest, as well as predicted effects on walking behavior consistent with the behavioral literature reviewed, are presented in Table 13. Predicted active transportation behavior, as well as the difference relative to the baseline, are presented in Table 14.

Table 13. Pre- and Post-project Built Environment Variables, BRRC

	Pre-project	Post-project	Change	Behavioral Response
Sidewalk Length	*5.0 mi*	*24.2 mi*	*+388%*	*Increase in average walking time:* ***46.6%***
Sidewalk Density	*2.0 mi/mi²*	*9.9 mi/mi²*	*+7.9 mi/mi²*	*Increase in odds of taking a walk trip:* ***11.2%***

Table 14. Post-Intervention Walking for Transportation, BRRC

BRRC Survey Results		Grouped Based on Risk Factor Categories		
Min. Transportation PA per Week	*Percentage of Population*	*Min. Transportation PA per Week*	*Percentage of Population*	*Change, Relative to Baseline*
0	*38.1%*	*0*	*38.1%*	**-2.5%**
1-84	*24.3%*	*1-149*	*36.2%*	**-4.6%**
85-116	*10.3%*	*1-149*	*36.2%*	**-4.6%**
117-140	*5.7%*	*1-149*	*36.2%*	**-4.6%**
141-168	*4.9%*	*150+*	*25.7%*	**+7.1%**
169+	*22.4%*	*150+*	*25.7%*	**+7.1%**

Based on these predicted changes in physical activity from walking for transportation, we predict significant positive health impacts. Fifty years after the construction of the project, 7 lives will be saved and approximately 1% of future cases of both diabetes and CHD will be avoided, along with around 0.7% of future cases of hypertension and 0.4% of future cases of stroke. These health impacts are shown though time for both genders in Figure 12. Lives saved are plotted on the left axis while the percentage of cases avoided for each health outcomes are plotted on the right axis. Health outcomes are disaggregated by gender for three time periods – 10, 20, and 40 years in the future – in Table 19.

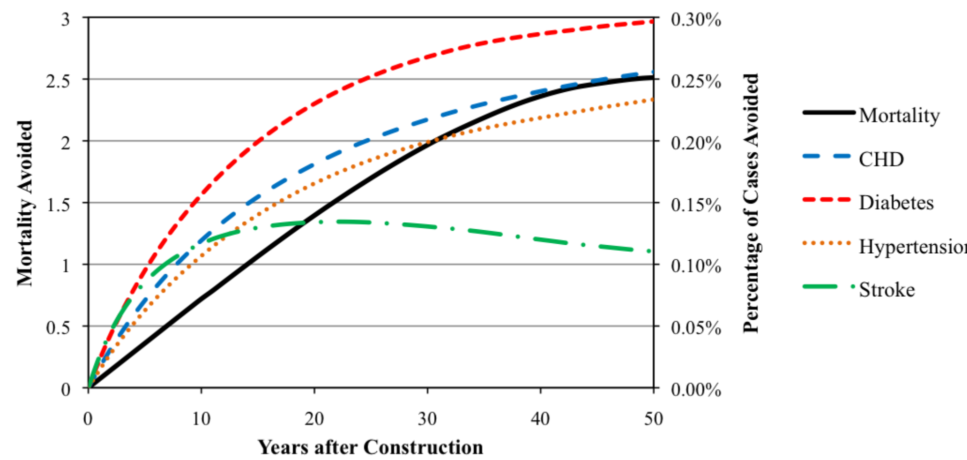

Figure 12. BRRC Predicted Health Outcomes

Intervention Data: Sparta

Pre- and post-project built environment variables of interest, as well as predicted effects on walking behavior consistent with the behavioral literature reviewed, are presented in Table 15. We assume that implementing all sidewalk improvements and street crossings as detailed in the Sparta Downtown Street Strategy will improve the PEF score from the lowest category to the middle category. Additionally, the construction of a new greenway segment would increase the total length of sidewalks and greenways in Sparta from 2.8 miles to 3.1 miles, resulting in an increased walking time amongst existing walkers of 43.2%, and would increase coverage from 1.2 miles of sidewalk per square mile of land area to 1.3 miles of sidewalk per square mile of land area, resulting in a negligible increase in the odds of someone taking a walking trip.

Predicted active transportation behavior after the proposed built environment change, as well as the difference relative to the baseline, are presented in Table 16. A large shift from the non-walking category into a walking category is predicted, as well as a moderate shift from the 1-150 minutes per week category into the greater than 150 minutes per week category.

Table 15. Pre- and Post-project Built Environment Variables, Sparta

	Pre-project	Post-project	Change	Behavioral Response
Downtown PEF	*Range: 4 to 8*	*Range: 8 to 12*	*+4*	*Increase in weekly walking distance:* ***0.57 miles per week***

Table 16. Post-Intervention Walking for Transportation, Sparta

Estimated Intervention Active Transportation Behavior		Grouped Based on Risk Factor Categories		
Min. Transportation PA per Week	*Percentage of Population*	*Min. Transportation PA per Week*	*Percentage of Population*	*Change, Relative to Baseline*
0	*75.0%*	*0*	*75.0%*	***-8.8%***
1-43	*13.2%*	*1-149*	*20.8%*	***+7.4%***
44-74	*3.3%*	*1-149*	*20.8%*	***+7.4%***
75-134	*3.0%*	*1-149*	*20.8%*	***+7.4%***
135+	*5.5%*	*150+*	*4.2%*	***+1.4%***

Based on these predicted changes in physical activity from walking for transportation, we predict significant positive health impacts. Fifty years after the construction of the project, 2 lives will be saved, and significant percentages of cases of CHD, Diabetes, Hypertension, and Stroke will be avoided. Modeled health impacts through time for both genders are shown in Figure 13. Lives saved are plotted on the left axis while the percentage of cases avoided for each health outcome are plotted on the right axis. Additionally, health outcomes are disaggregated by gender for three time periods – 10, 20, and 40 years in the future – in Table 20.

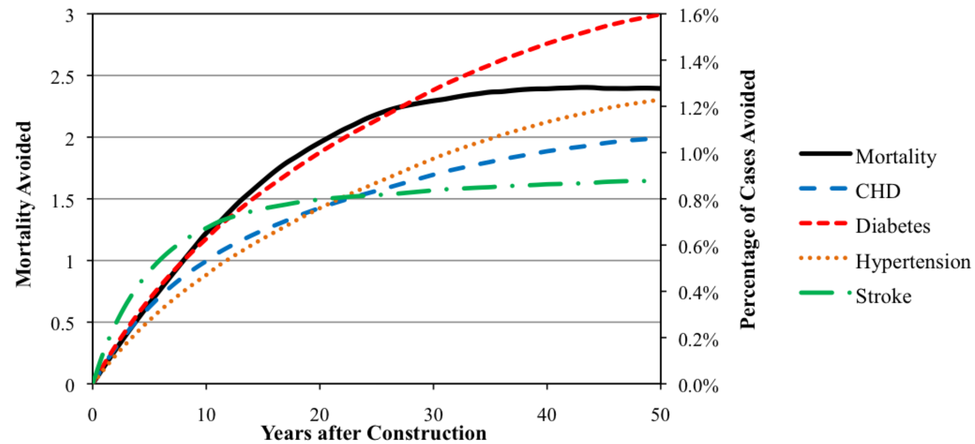

Figure 13. Sparta Predicted Health Outcomes

Economic Implications

While health outcomes are important in and of themselves, it is difficult to compare health to other outcomes without a consistent frame of reference. This is especially critical for the allocation of funds for transportation projects, wherein a large number of projects compete for funds that are limited relative to funding needs. In order to demonstrate the economic value of improved health outcomes attributable to active transportation infrastructure, we used established values for an individual's life and yearly disease cost to estimate total economic benefits to society resulting from improved health outcomes.[32-33] Health outcome valuations are detailed in Table 17. To account for reduced present value of health outcomes predicted to occur in the future, we used a traditional discounting procedure, in which the present value (PV) of a future income stream, C, received over k years in the future is adjusted based on a discount rate, d:

$$PV = \sum_{k=1}^{n} C(1+d)^{-k}$$

Selecting an appropriate discount rate is a contentious issue when monetizing health outcomes. Some argue that the future value of life should not be discounted, supporting a 0% discount rate, while others argue for a more traditional discounting approach. However, some recent work supports a discount rate between 3% and 4%.[34-35] We estimated the present value of health impacts using three discount rates to account for this uncertainty: 3.5%, 5%, and 7%. The Office of Management and Budget (OMB) requires federal agencies to use a 7% discount rate;[36] however, USDOT suggests a lower discount rate (5%) when considering the value of statistical life.[33] We consider the OMB recommended discount rate of 7%, a low case (3.5%) to match assumptions elsewhere in WalkBikeNC and to be consistent with recent literature,[35] and one intermediate case. We summarize the estimates at three points in the future that are useful from a decision-making perspective: 10, 20, and 40 years. Additionally, we estimate project costs, using either costs provided in the project documentation or new estimates based on per unit construction costs and compare them to projected benefits. While this simple cost-benefit analysis (CBA) is rather crude, it illustrates a manner in which these results can be included in decision-making processes. A benefit-cost ratio equal to 1 suggests that the project would have no net financial benefit to society, a ratio less than 1 suggests the project would be a net financial loss, and a ratio greater than 1 suggests that the project would be a net gain.

Table 17. Health Outcome Monetization Sources

Health Outcome	Monetary Value (2009 USD)	Source
CHD	*$9,048 per case per year*[a]	*An Unhealthy America: The Economic Burden of Chronic Disease*[32]
Diabetes	*$9,844 per case per year*[a]	*An Unhealthy America: The Economic Burden of Chronic Disease*[32]
Hypertension	*$8,831 per case per year*[a]	*An Unhealthy America: The Economic Burden of Chronic Disease*[32]
Stroke	*$15,573 per case per year*[a]	*An Unhealthy America: The Economic Burden of Chronic Disease*[32]
Mortality	*$8,600,000 per statistical life*[b]	*Guidance on Treatment of the Economic Value of a Statistical Life in USDOT Analyses*[33]

[a]Monetary value for North Carolina *[b]Monetary value for the United States*

Economic Valuation: Winterville

The estimated present value, in 2012 dollars and for each discount rate assumed, for the health impacts of the Winterville projects in the Pitt County Bicycle and Pedestrian Master Plan are shown in Figure 14. Full results are summarized in Table 18 for 10, 20, and 40 years post project construction, assuming a 3.5% discount rate and including project costs. We estimate the value of reduced mortality and reduced incidence of CHD, diabetes, hypertension, and stroke attributable to build-out of the Greenville MPO Bicycle and Pedestrian Master Plan to reach nearly $9,000,000 20 years after construction and exceed $12,500,000 within 40 years of construction. These projected economic benefits exceed estimated project cost by a factor of 0.5 to slightly above 1.0, increasing over time.

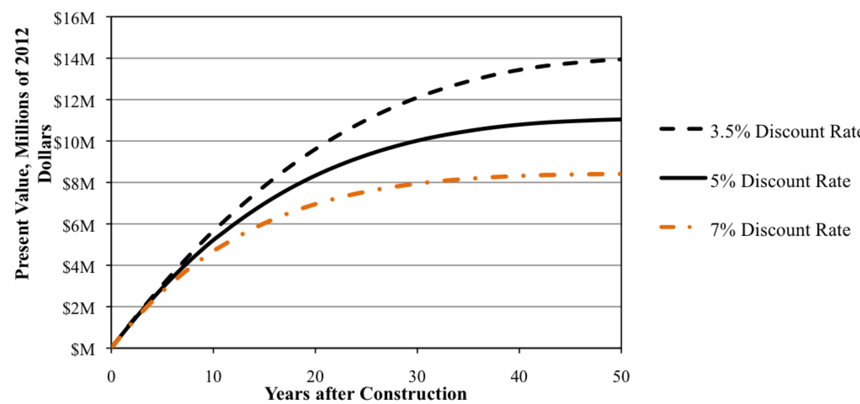

Figure 14. Winterville Economic Valuations

Table 18. Complete Winterville Results

	10 Years Post Construction			20 Years Post Construction			40 Years Post Construction		
Avoided Cases of:	Men	Women	Total	Men	Women	Total	Men	Women	Total
Mortality	0.4	0.4	0.7	0.7	0.7	1.4	1.2	1.2	2.4
CHD	0	0.3	0.3	0	0.5	0.5	0	0.7	0.7
Diabetes	0.4	0.6	1.0	0.7	1.0	1.7	1.1	1.5	2.6
Hypertension	1.1	1.4	2.5	2.0	2.4	4.4	2.9	3.6	6.5
Stroke	0.2	0.2	0.4	0.3	0.3	0.6	0.3	0.4	0.7
Economic Value	**$5,290,000**			**$8,980,000**			**$12,550,000**		
Cost Estimate	**$11,088,000**			**$11,088,000**			**$11,088,000**		
Benefit-Cost Ratio	**0.48**			**0.81**			**1.1**		

Economic Valuation: BRRC

The estimated present value, in 2012 dollars and for each discount rate assumed, for the health impacts of the BRRC small area plan are shown in Figure 15. Full results are summarized in Table 19 for 10, 20, and 40 years post project construction, assuming a 3.5% discount rate and including project costs. We estimate that the health impact of build-out of the BRRC small area plan will eclipse $25,000,000 within 20 years of construction and continue to rise above $36,000,000 40 years post-construction. Thus, we estimate that the benefits of active transportation infrastructure components of the BRRC plan will exceed the costs of construction by a factor of 4 to 9, once again increasing over time.

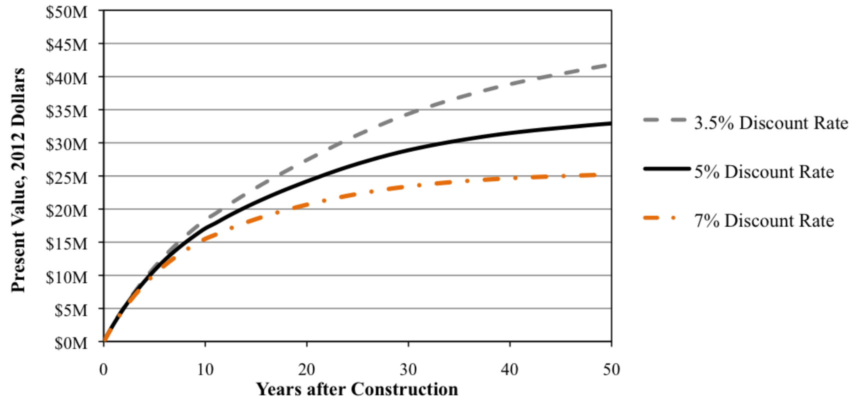

Figure 15. BRRC Economic Valuations

Table 19. Complete BRRC Results

	10 Years Post Construction			20 Years Post Construction			40 Years Post Construction		
Avoided Cases of:	Men	Women	Total	Men	Women	Total	Men	Women	Total
Mortality	1.0	1.3	2.3	1.8	1.8	3.7	3.3	3.1	6.4
CHD	0	1.4	1.4	0	2.7	2.7	0	4.5	4.5
Diabetes	1.6	2.1	3.7	3.0	3.9	6.9	5.0	6.5	11.5
Hypertension	5.2	4.2	9.4	7.5	9.5	17.0	11	14.3	25.3
Stroke	0.7	0.9	1.6	1.2	1.7	2.9	1.8	2.5	4.3
Economic Value		**$17,180,000**			**$25,610,000**			**$36,300,000**	
Cost Estimate		**$4,055,040**			**$4,055,040**			**$4,055,040**	
Benefit-Cost Ratio		**4.2**			**6.3**			**9.0**	

Economic Valuation: Sparta

The estimated present value, in 2012 dollars and for each discount rate assumed, for the health impacts of the Downtown Sparta Streetscape Strategy are shown in Figure 16. Full results are summarized in Table 20 for 10, 20, and 40 years post project construction, assuming a 3.5% discount rate. Given a typical project lifespan of 20 to 40 years, we predict that the health outcomes associated with implementation of the Downtown Sparta Streetscape Strategy will exceed the costs by a factor in the range of 13 to 22.

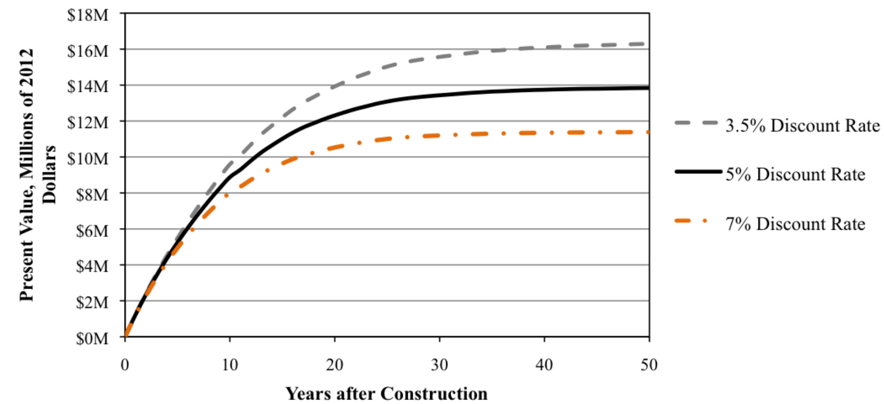

Figure 16. Sparta Economic Valuations

Table 20. Complete Sparta Results

	10 Years Post Construction			20 Years Post Construction			40 Years Post Construction		
Avoided Cases of:	Men	Women	Total	Men	Women	Total	Men	Women	Total
Mortality	0.6	0.6	1.2	1.0	1.0	2.0	1.3	1.1	2.4
CHD	0.1	0.5	0.6	0.1	0.7	0.8	0.2	0.8	1.0
Diabetes	0.4	0.6	1.0	0.7	1.0	1.7	1.0	1.3	2.3
Hypertension	1.0	1.3	2.3	1.7	2.0	3.7	2.3	2.6	4.9
Stroke	0.2	0.4	0.6	0.3	0.5	0.8	0.3	0.6	0.9
Economic Value	**$8,960,000**			**$13,010,000**			**$15,040,000**		
Cost Estimate	**$686,257**			**$686,257**			**$686,257**		
Benefit-Cost Ratio	**13.1**			**19.0**			**22.0**		

9.4

Assessment: Limitations

While the quantitative methods applied in this study represent the state of the art in HIA, several limitations should be addressed. First, our model does not explicitly consider obesity due to a lack of relative risk data linking walking for transportation to overweight/obesity. However, this may represent the lack of a direct causal linkage between non-vigorous physical activity and overweight/obesity when controlling for confounding factors such as diet. Further, the uncontrolled RR values selected linking the disease in our model to walking for transportation do not control for obesity, thereby implicitly assuming a similar prevalence of overweight and obesity in the study population used in the epidemiological study and the populations in our three study areas. Regardless, the inability of our model to explicitly consider obesity likely results in more conservative model results. Similarly, data limitations at the county level for cancer prevalence and incidence by age and sex prevent the inclusion of these health outcomes in our model. However, the prevalence of cancer is small; thus, the change in prevalence relative to the baseline would likely be limited in this assessment should we have been able to include cancer outcomes. Finally, Chronic Obstructive Pulmonary Disease (COPD) is not considered due to limited epidemiological evidence linking non-vigorous physical activity to the prevalence or incidence of COPD, although evidence does recommend physical activity as a means to reduce mortality in those already diagnosed with COPD.[37] This likely does not bias our results because changes in mortality in individuals diagnosed with COPD would be included in a population-level all-cause mortality relative risk for physical activity, assuming prevalence of COPD is roughly similar across populations. In sum, diseases not included in this assessment likely result in a small, conservative under-estimate of total health benefits.

A second limitation arises from the nature of the Behavioral Risk Factor Surveillance System (BRFSS) data used to estimate population prevalence and incidence. The BRFSS question listed in Table 7 asks whether respondents have ever been told that they have a given disease; thus, the prevalence of reversible diseases (e.g. hypertension) is likely over-estimated. While the incidence estimation results in its own uncertainty, this is compounded for reversible disease with potentially unreliable prevalence estimates. However, the data used for this HIA are the most accurate publicly available data sources for disease prevalence.

A third significant limitation is the uncertainty associated with transportation behavior estimates. While the estimates are generally feasible and supported by a growing body of literature, the majority of travel behavior studies focus on trip numbers or mode choice – which are important for transportation planners but less so for public health practitioners – rather than trip duration or distance. Therefore, estimates in this report are based on single studies and subject to uncertainties when applied to other geographic areas. Additionally, in the Sparta study area, the built environment variable used is based on subjective criteria (sidewalk and crossing quality) and is not statistically significant in the model used by Boarnet et al. However, we use the lowest model coefficient and assume a modest change in Pedestrian Environment Factor to be conservative. We also assume that only 25% of the Town of Sparta – the area of the town within a 0.25 mile buffer of the proposed street improvements – is affected by this built environment change.

Finally, we consider only walking for transportation and do not consider cycling for transportation or purely recreational physical activity (i.e., from recreationally using a greenway). Behavioral studies linking built environment characteristics to cycling behavior and purely recreational physical activity from transportation are limited. These limitations result in conservative estimates of post-intervention physical activity from transportation, particularly in Winterville and the BRRC where topographical constraints do not present a barrier to cycling. While not considered in this assessment, these domains of physical activity may be included in future iterations of this model as behavioral studies improve.

The complexity of DYNAMO-HIA presents a significant limitation for wider use of the methods performed in the assessment. However, the depth and quantitative nature of the findings warrant a significant effort to adapt DYNAMO-HIA model components into a more user-friendly package. Further, the DYNAMO-HIA model was applied despite significant data limitations; thus, a similar model with a more user-friendly interface would likely be extremely useful to researchers and practitioners alike interested in quantitative HIA methods.

Recommendations

From the findings of this report, we developed three broad sets of recommendations: 1) Project-specific recommendations; 2) Recommendations from WalkBikeNC that are directly supported by this analysis; and 3) Recommendations for practice. These are summarized below:

Project-specific recommendations: Winterville

1. Build out sidewalk network in Winterville as proposed in the Greenville Bicycle and Pedestrian Master Plan
2. Use modeled health impacts to help advocate for funding from potential funding sources, as identified in the Greenville Bicycle and Pedestrian Master Plan
3. Investigate programs to counteract negative perceptions (both stigmas and elitist perception) of active transportation behavior in the community
4. Coordinate with local institutions to include active transportation-related questions in future local surveys

Project-specific recommendations: BRRC

1. Coordinate with NCDOT to ensure that reconstruction of all state owned right-of-way in the project area is accompanied by construction of sidewalks on both sides of the street
2. Ensure that all new roads in the study area are initially built with sidewalks on both sides of the street
3. Coordinate with local partners (state of North Carolina, Art Museum, etc.) to explore creative funding options for sidewalks infrastructure

4. Coordinate with local institutions to include active transportation-related questions in future local surveys

Project-specific recommendations: Sparta

1. Build out the pedestrian improvements as proposed in the Sparta Downtown Streetscape Strategy
2. Leverage the results of this report to advocate for funding from a variety of potential partners
3. Coordinate with local institutions to include active transportation-related questions in future local surveys

Supported WalkBikeNC recommendations:

Mobility

1. Expand community-oriented pedestrian facilities
2. Provide pedestrian and bicycle access to transit

Safety

1. Create a strategic, consistent, and connected pedestrian and bicycle network

Public Health

1. Increase active living environments
2. Increase the safety, connectivity, and accessibility of the bicycle and pedestrian network
3. Improve public health outcomes

Economic Competitiveness

1. Increase attractiveness and quality-of-life through walkable and bikeable communities
2. Measure return on investment of active transportation investments
3. Use return on investment analyses to inform transportation decision-making

Recommendations for research and practice:

1. Develop improved data infrastructure for the following:

   a. Sidewalk and bicycle networks

   b. More refined prevalence data for cancer (by type), CHD, diabetes, hypertension, and stroke.

2. Ensure that future studies of the built environment and travel behavior report active travel in units relevant to epidemiological studies (i.e., minutes of physical activity rather than mode choice, number of trips, or reductions in vehicle miles travelled)
3. Using optional state-specific questions, include active transportation as a regularly asked question in the BRFSS (e.g., 2009 North Carolina BRFSS)
4. Develop local capacity to conduct HIAs by providing training, technical assistance, and other resources.
5. Advance HIA methods to focus on methods that help inform decisions on proposed policies, plans, and development from a quantitative perspective, including the use of monetization of health impacts.
6. Develop a practitioner-focused tool that combines a Marko Chain approach with a more user-friendly interface and linked to publicly available data sources.

Reporting

The findings of this report will be disseminated in three ways: 1) inclusion in WalkBikeNC; 2) presentation of results to local leaders and decision-makers in each HIA community; 3) presentation at appropriate public meetings and venues; and 4) publication in academic literature and presentation at appropriate academic conferences.

This report is included in its entirety as a technical appendix in the North Carolina Statewide Bicycle and Pedestrian Master Plan, known as WalkBikeNC. Further, a brief summary and key HIA findings appear within the main text of the plan.

Post-project meetings will be held in each community to present results and obtain feedback from local leaders and decision-makers in each community.

A brief presentation highlighting the findings of this analysis, as well as broad lessons learned, will be presented as appropriate meetings as part of the post-WalkBikeNC period. Meetings that will be targeted include outreach meetings with WalkBikeNC stakeholders, community transformation grant meetings, and Municipal Planning Organization (MPO) and/or Rural Planning Organization (RPO) meetings in each project region.

The results of this analysis will also be translated into an academic paper to be submitted to an appropriate journal and will be submitted for presentation at academic conferences such as the National Health Impact Assessment (HIA) Meeting. These publications will focus on the technical methods, limitations, and implications for future work – with the aim of developing a user-friendly, practitioner-ready quantitative HIA tool in the future.

Monitoring and Evaluation

Looking to the future, monitoring and evaluation should focus on the build-out of the projects as analyzed in this report as well as changes in active transportation behavior in each community. While health outcomes are measured over time, the predicted magnitude of change and the large number of external factors that may affect health outcomes prevent a significant barrier to using health outcomes for evaluation. Active transportation behavior, however, is a more sensitive intermediary and can be used as a proxy for health outcomes with proven links to physical activity from transportation. Build-out of projects provides a more tangible measure and is a suitable proxy for the efficacy of local institutions in providing funding for active transportation infrastructure in their community. Along with these measures, efforts should be made to capture perceptions of active transportation in each community and document changes over time that may be attributable to infrastructure changes, active transportation programs, and/or demographic or cultural shifts. These data could be collected opportunistically as potential partners administer related surveys in each community over time.

Acknowledgements

We wish to acknowledge the contributions of all members of the Health Advisory Team, and meeting and focus group participants in each community. Special thanks are due to the North Carolina Department of Transportation (NCDOT) for supporting this research, Alta/Greenways for assisting with data collection efforts and providing oversight, and Active Living By Design for providing valuable support, guidance, and editorial assistance throughout the assessment process.

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Appendix 1: Health Advisory Team

Participant	Organization
Lauren Blackburn	*NC Department of Transportation*
Julie Hunkins	*NC Department of Transportation*
Helen Chaney	*NC Department of Transportation*
Lori Rhew	*NC Department of Health and Human Services*
Ruth Petersen	*NC Department of Health and Human Services*
Monique Bethell	*NC Department of Health and Human Services*
Chuck Flink	*Alta/Greenways*
Matt Hayes	*Alta/Greenways*
Jackie Epping	*Centers for Disease Control and Prevention*
Candace Rutt	*Centers for Disease Control and Prevention*
Jennifer MacDougall	*Blue Cross Blue Shield of NC Foundation*
Jackie MacDonald-Gibson	*UNC Environmental Sciences and Engineering*
Ted Mansfield	*UNC Environmental Sciences and Engineering*
Tim Schwantes	*UNC Active Living By Design*
Philip Bors	*UNC Active Living By Design*

Appendix 2: Community Meeting Documentation

Winterville

Participant	Organization
Jo Morgan	*Pitt County*
James Rhodes	*Pitt County*
Daryl Vreeland	*Greenville MPO*
Jennifer Smith	*Vidant Health*
Alan Lilley	*Town of Winterville*

The meeting began with a broad scoping exercise designed to identify a wide range of factors that may have negative health impacts in the community. Broadly, the participants identified several built environment factors that may negatively affect health outcomes in Winterville, including non-walkable development scales, car-oriented development, segregated land uses, lack of services and employment within Winterville proper, and school siting. Participants also identified demographic and cultural factors, including poverty and a high prevalence of risk factors, as negative influences on the health of their community. Specific to physical infrastructure in Winterville, participants identified the lack of sidewalks, poor sidewalk connectivity between developments that do contain sidewalks, road widening projects undertaken without supplementary improvements such as the addition of sidewalks and bike lanes, and physical barriers presented by NC11 and the railroad tracks that bisect Winterville as having a potentially negative effect on public health. Considering services, participants identified the lack of public transit and poor access to facilities that offer affordable healthcare as potential detriments to public health. The participants also noted that Winterville has successfully employed joint-use agreements in many schools to provide recreational facilities outside of school hours; however, the positive health impacts of these agreements may be limited due to poor school siting and poor bicycle and pedestrian infrastructure around schools. Considering social and/or economic conditions that may impact health, the participants noted concern over the stigmatized perception of walking and biking as a mode of transportation (rather than recreationally) in Winterville. They also stressed the importance of correctly framing the message to encourage active transportation as a normative rather than elitist behavior. Participants also identified concerns over poor awareness of drivers, cyclists, and pedestrian of the "rules of the road" in multi-modal situations. Finally, the participants expressed concerns over the degree to which NC11 degrades the natural environment and, in turn, public health, due to noise and air pollution. The overall aesthetic quality of many streetscapes, including NC11, was also identified as negatively influencing public health ("there are sidewalks on NC11, but who would want to walk on them?") Overall, three themes emerged in discussing determinants of health in broad terms: 1) Underlying socio-demographic characteristics and cultural norms, 2) Inadequacies in physical infrastructure, and 3) Land use patterns.

Upon concluding the broad scoping exercise, a more focused exercise was conducted to gain further insight relevant to the Bicycle and Pedestrian Master Plan. Focusing specifically on physical inactivity as a determinant of health, the participants identified the lack of physical infrastructure, specifically outside of downtown and outside of newer subdivisions built in the wake of subdivision regulations requiring the construction of sidewalks, as the primary barrier to increasing physical activity. Participants noted that lack of physical activity is a risk factor for a range of health outcomes including overweight/obesity, heart disease, mental health, etc. Susceptible populations were identified primarily based on geography rather than socio-demographic characteristics; that is, the workshop participants felt that neighborhood quality was a more important than individual characteristics in explaining the propensity to use physically active transportation modes. A final point that was made during discussion is that it is important to "make infrastructure a part of your day," reinforcing the need to frame active transportation in a way that helps develop a positive cultural norm for its use, rather than an elite activity for the "lycra crowd." The two-phased scoping exercise conducted in Winterville provided the project team with invaluable information regarding the broad contextual drivers of health outcomes in the community as well as specific concerns relevant to the Pedestrian and Bicycle Master Plan. Further, a brief discussion of framing the message encouraged the use of economic development, quality of life, and social equity as frames to discuss active transportation. However, it was also noted that it is difficult to get chronic disease on the public agenda because of historic emphasis on communicable disease as well as the view that "health is only important until you don't have it" – providing support for frames other than public health to discuss active transportation.

An informal discussion followed on a variety of issues, including other relevant projects that may be included in the analysis and potential sources for more granular health data. The participants encouraged the project team to consider several of the broader infrastructure recommendations included in the Bicycle and Pedestrian Master Plan, including improvements to Old Tar Road and NC11. In response to this request, the project team will likely prepare two implementation scenarios – one including only projects identified as "Priority Projects" in the plan and one including these projects as well as several additional projects high-profile identified in the plan – in addition to the "do-nothing" scenario. Regarding data, participants stressed that Pitt County is a Behavioral Risk Factor Surveillance System (BRFSS) oversampled county, so risk factor data are more robust than in many other geographies.

Sparta

Participant	Organization
Jennifer Greene	*Appalachian Health District*
Kevin Dowell	*Town of Sparta*
Bryan Edwards	*Sparta Town Manager*
Jane Wyatt	*Town of Sparta*
Eric Woolridge	*Destination by Design*
Teresa Buckwalter	*Destination by Design*
Beth Fornadley	*Appalachian Health District*
Rachel Miller	*Appalachian Health District*

The meeting began with a broad scoping exercise designed to identify a wide range of factors that may have negative health impacts in the community. Broadly, the participants identified several built environment factors that may negatively affect health outcomes in Sparta, including: 1) incomplete sidewalk network, 2) heavy traffic along key routes, 3) segregated land uses, and 4) rural school siting. Participants also identified demographic and cultural factors including: 1) poverty, 2) age (older population), 3) high proportion of population lacking health insurance, 4) a cultural bias towards the car due in part due to Sparta's rural setting, 5) poor nutrition/access to healthy foods, and 6) cultural norms regarding tobacco use. Specific to physical infrastructure in Sparta, participants identified the lack of sidewalks, the width and quality of existing sidewalks (an example of a sidewalk with an electrical pole in the middle was given), the lack of passing zones (to pass cyclists) on rural roads, and the large lane widths on roads throughout Sparta (encouraging high travel speeds) as having a potentially negative effect on public health. However, the participants also identified several new trails that have been completed recently in Sparta and anecdotally characterized the use of these trails as fairly significant. Considering services, participants identified the lack of public transit and the fragmentation of government services downtown (i.e., previously, residents would "park once" in downtown and walk to use government services, but now that services are offered in different buildings, individuals seem more likely to drive to each building) as negatively affecting health. Considering social and/or economic conditions that may impact health, the participants noted that walking is stigmatized in the community and that several economic conditions, including a large parentage of the population of fixed incomes and a large number of seasonal workers, may have a negative influence on public health. However, the participants did note that Sparta has a strong sense of community and that there are generally a large number of active volunteers in the community, which may improve well-being directly and may be leveraged to counteract the negative walking stigma in the future. Participants also identified concerns over proper education of drivers and cyclists and inconsiderate behaviors of drivers towards pedestrians in general. Finally, the participants noted that, while the natural environment of Sparta is largely pristine, the aesthetics of downtown are not conducive to walking. Further, the extreme elevation changes in the community make cycling very difficult and thus more of a recreational activity. Additionally, participants noted that Sparta does have a great deal of open space, but lacks programmed open space (i.e., sports fields, playground equipment, etc.) which may reduce the effectiveness of open space as a recreational resource. Overall, three central themes emerged in our broad discussions of health determinants in Sparta: 1) the real and perceived safety of pedestrians, including the perception of pedestrians from the drivers' point of view, 2) inadequacies in physical infrastructure, and 3) difficulties associated with high prevalence of poverty and a high number of seasonal workers/population. Similar to the meeting in Winterville, framing the message was stressed at several points during the scoping exercise. Participants in Sparta suggested framing active transportation as an issue of personal choice: expanding infrastructure that is supportive of physically active transportation expands personal choice and gives individuals a new opportunity to choose to be physically active as part of their daily routine.

A more focused scoping exercise was also conducted to gain additional information relevant to the Downtown Sparta Streetscape Strategy. Focusing specifically on physical inactivity as a determinant of health, the participants identified the lack of safe opportunities to cross the street, high traffic speed, and traffic signaling that is unsafe for pedestrians (e.g., right turn green arrows and protected right turn lanes) as primary barriers to increased walking due to negative effects (real and perceived) on pedestrian safety. Participants did not consider bicycling due to natural environment factors (e.g., steep slopes) that present significant barriers to cycling. Participants also identified several sub-populations that may be impacted by targeted improvements, including students who are unable to walk to school due to gaps in the sidewalk network, seasonal workers who do not have a car and must walk to work since there is no public transit, and carless households that also must rely on walking as a primary mode of transportation. The scoping exercises conducted in Sparta provided some insight into cultural, social, and economic drivers of health outcomes in the community in addition to specific health concerns relevant to the Downtown Streetscape Strategy and specific sub-populations that may be more affected than others by the plan.

After completing the discussion on scoping, a brief discussion on data sources and complementary projects in Sparta was conducted. A number of projects were identified, including a greenway plan and a pedestrian plan that may be used to develop an additional implementation scenario at the discretion of the project team. It was stressed that, while Census data for Sparta are not geographically specific, several additional sources of data are available that may be useful, including physical activity survey data from a recent county recreational plan.

Blue Ridge Road Corridor

A discussion guide was developed to guide focus group participants through a discussion of the breadth of health concerns, real, potential and/or perceived, that are known to people who live, work and visit the BRRC. During 1.5 hours of facilitated discussion, focus group participants were asked to provide thoughts and comments on the following three general topics:

1. What elements of the BRRC neighborhood and environment, as it currently exists, do stakeholders identify as a concern to public health?
2. What health effects, both positive and negative, can be identified in the BRRC that might be affected through planning, design, and change to infrastructure?
3. How can existing plans or conceptual designs for the BRRC address specific health concerns?

Facilitators began each session by briefly introducing the City of Raleigh's Blue Ridge Road District Study and outlined HIA methods and the objectives of the Blue Ridge Road Corridor Health Impact Assessment Project. A discussion then followed based on the outline of the discussion guide with details and examples provided by the facilitator to ensure discussion of all relevant topic areas and contribution by all focus group participants.

Focus group participants were recruited from citizens and officials who had attended the City of Raleigh's February 9, 2012 Blue Ridge Road Corridor design charrette and from contacts provided by the Blue Ridge Road Corridor Health Impact Assessment Project advisory committee. Focus group meeting times and locations were selected to provide opportunities for a broad range of stakeholders to participate. Evening meetings were held to allow residents from neighborhoods both north and south of Wade Avenue to attend and lunch time meetings were scheduled to allow business owners, those employed in the BRRC, and government officials to attend.

The group of 40 participants was primarily composed of people employed within the BRRC (14), residents of neighborhoods adjacent to the BRRC (12) or officials from the City of Raleigh, Wake County or state agencies (11). Two people with business interests along the corridor and one planning student also participated. All focus group participants were familiar with at least some portion of the BRRC from personal and/or professional experiences.

Focus group participants raised over 70 concerns about threats to public health in the BRRC. 17 of these concerns were raised in more than one focus group and 11 concerns were raised the majority of focus group meetings. Only one concern, the lack of adequate sidewalks in the BRRC area, was identified as a public health concern in all five focus groups.

Focus group meetings are summarized below:

Location	Date	Attendees	Notes
Private residence in the Westover community, adjacent to the State Fairgrounds	*February 28th 2012*	*6*	*Stakeholders present were all neighbors of the BRRC (6)*
Urban Design Center, downtown Raleigh	*March 1st 2012*	*9*	*Stakeholders present were state and local officials, also were members of the BRRC HIA Advisory Council (9)*
Wake Internal Medicine Building, 3100 Blue Ridge Road	*March 6th 2012*	*7*	*Stakeholders present were primarily neighbors of the BRRC north of Wade Avenue (6) and one member who was a business owner with property interest along the BRRC (1).*
North Carolina Museum of Art, 2110 Blue Ridge Road	*March 8th 2012*	*12*	*Stakeholders present all employees or volunteers of the NC Museum of Art (12).*
NCSU Vet School	*March 20th 2012*	*6*	*Participants in this focus group were a mix of stakeholder types including local officials (2), employees working within the BRRC (2), a local business owner (1) and a student of urban design (1).*

Eight concerns to public health that were raised by a majority of focus groups and that were described as having relatively high weight as a concern to public health:

- Lack of adequate sidewalks/crosswalks
- Intersections and roads designed primarily for cars
- Lack of public transportation
- Drunk/distracted drivers
- Lack of efficient road system
- Lack of clear trail indicators (signs, maps, etc.)
- Large gaps between pedestrian destinations
- Not all pedestrian facilities open at night

Focus group participants identified 19 health impacts related to development of the BRRC. Five of these health impacts were raised in more than one focus group and two health impacts, stress and safety from injury, were identified as a public health concern in all five focus groups. Safety from injury was the one health impact identified by all focus groups and weighted as relatively important compared to other health impacts.

Focus group participants identified 27 potential changes to the BRRC that could positively impact public health. Twelve of these ideas were raised in more than one focus group and one idea, improving the aesthetics of the BRRC environment was raised at every focus group meeting.

Seven ideas to improve public health that were raised by a majority of focus groups:

1. Make BRRC more aesthetically pleasing
2. Sidewalks/crosswalks on major roads
3. Build more things to walk to (coffee shops, restaurants, etc.)
4. Bike lanes/bike racks
5. Improved connections to and between modes of public transit
6. Educational opportunities
7. Better publicity, signage, maps, etc.

Broadly, the major themes expressed by focus group participants are as follows:

- A lack of sidewalks and crosswalks is a serious threat to public health.
- Design of the BRRC roads at present does not well serve non-vehicular transportation.
- The BRRC is perceived as a dangerous area due to the potential for injury on streets.
- A lack of convenient public transportation is perceived as a deterrent to public health.
- The environment of the BRRC is perceived as stressful.
- Environmental degradation and/or improvements from development activities were perceived as important, but not clearly linked to public health in the BRRC.
- Noise and light pollution were perceived as important, but not strongly linked to public health in the BRRC.
- Limited signage and wayfinding materials limit pedestrian and bicycle travel.
- Lack of bicycle lanes and bicycle parking identified as limits to bicycle transportation to and within the BRRC.
- Large gaps exist between existing destinations along the corridor, limiting pedestrian and bicycle travel.
- Efforts to increase the density of service and recreational destinations along the BRRC perceived as a positive effort to support public health.
- Efforts to improve the aesthetic feel of the BRRC perceived an important role in public health.

Appendix 3: Technical Methods

Population Age Distribution Estimation

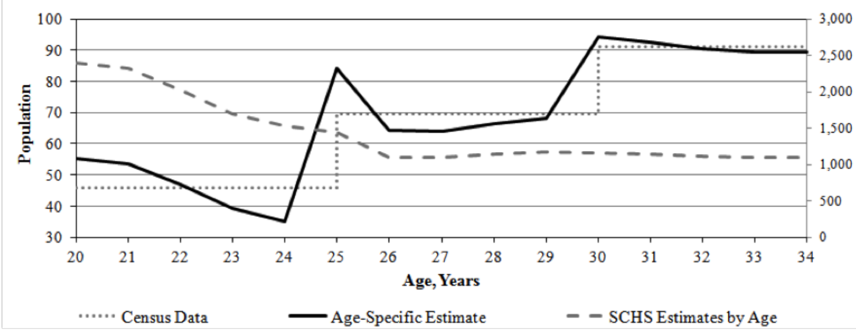
The DYNAMO-HIA requires baseline population estimates for all ages ranging from 0-95; however, census data are given in larger age groups. The NC SCHS provides county-level population estimates by sex and age. We use the distribution of the SCHS population by age to estimate the distribution of population by age within each census age group, holding the total population in each census age group constant. To do this, we do the following for each sex:

1. Calculate the percentage of SCHS population at each age as a percentage of total population in the associated census age group
2. Multiply census data grouped populations by the appropriate SCHS population percentage

An example calculation and graphical representation of the process are presented to the right:

	County-Wide Data						Study Area Data					
	NC SCHS Estiamtes			Percentage, by Census group			Census Data			Age-Specifc Estimates		
	Gender		Total	*Gender*		Total	*Gender*		Total	*Gender*		Total
Age	Female	Male		Female	Male		Female	Male		Female	Male	
↑												
20	2,401	2,020	4,421	24.1%	22.0%	23.1%	230	186	416	**55**	**41**	**96**
21	2,314	2,062	4,376	23.2%	22.5%	22.9%	↓	↓	↓	**53**	**42**	**95**
22	2,029	1,922	3,951	20.4%	21.0%	20.6%				**47**	**39**	**86**
23	1,697	1,693	3,390	17.0%	18.5%	17.7%				**39**	**34**	**74**
24	1,526	1,474	3,000	15.3%	16.1%	15.7%				**35**	**30**	**65**
25	1,439	1,446	2,885	24.2%	22.9%	23.6%	347	230	577	**84**	**53**	**136**
26	1,103	1,398	2,501	18.6%	22.2%	20.4%	↓	↓	↓	**64**	**51**	**118**
27	1,098	1,318	2,416	18.5%	20.9%	19.7%				**64**	**48**	**114**
28	1,135	1,073	2,208	19.1%	17.0%	18.0%				**66**	**39**	**104**
29	1,167	1,071	2,238	19.6%	17.0%	18.3%				**68**	**39**	**105**
30	1,162	1,033	2,195	20.7%	20.8%	20.7%	456	384	840	**94**	**80**	**174**
31	1,141	1,005	2,146	20.3%	20.2%	20.3%	↓	↓	↓	**93**	**78**	**170**
32	1,114	985	2,099	19.8%	19.8%	19.8%				**90**	**76**	**166**
33	1,100	971	2,071	19.6%	19.5%	19.6%				**89**	**75**	**164**
34	1,101	978	2,079	19.6%	19.7%	19.6%				**89**	**76**	**165**
↓												

Example Age-specific Population Estimate: Female Population in Winterville



9.4

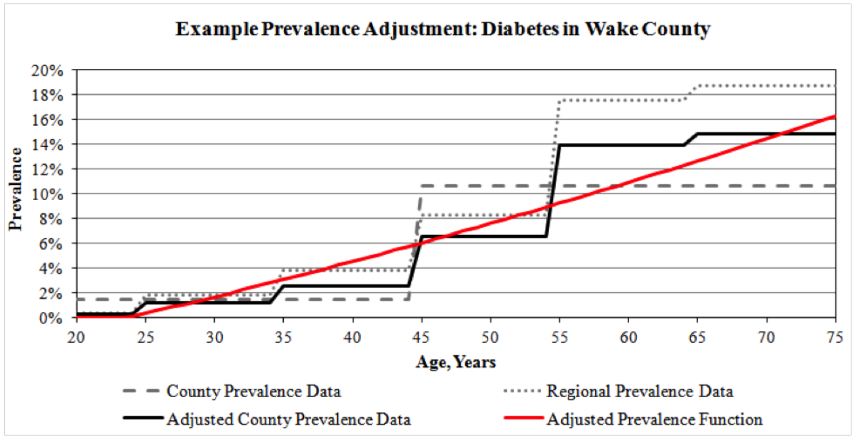
Population Disease Prevalence Estimation

Like population data, the DYNAMO-HIA requires age-specific baseline prevalence estimates for each disease specified. We use 2009 BRFSS data to estimate these values; however, these data are reported in two age groups at the county level and six age groups at the regional level. We follow a conceptually similar process as for population data as described previously. We use the finer-grained regional disease prevalence rates to estimate prevalence rates in the same age ranges at the county level constrained to given disease prevalence in the larger age ranges at the county level. To do this, we do the following for each disease:

1. Calculate the number of individuals in each county-level age group with each disease using 2009 NC SCHS population estimates and county-level prevalence estimates
2. Calculate the number of individuals in each regional age group with each disease using 2009 NC SCHS population estimates and regional prevalence estimates
3. Sum the total number of individuals with the disease from the regional prevalence estimates applied to county population (i.e., sum values from #2 into county-level age groups)
4. Calculate an adjustment factor, equal to the sum from #3 divided by the total from #1
5. Adjust the county-specific prevalence estimates using the six regional age groups by the adjustment factor calculated in #4
6. Use the six age group prevalence estimates to fit a second-order continuous prevalence function, assuming each prevalence value occurs at the population-weighted age midpoint of the six age groups
7. Use the continuous function above to estimate disease prevalence at 1-year intervals (i.e., 0, 1, 2, 3, etc.); subject to the following:
    - Disease prevalence below age 18 is always zero;
    - Disease prevalence is always positive;
    - Disease prevalence always increases with age (if a portion of the prevalence curve had a negative slope, values prior to the low point of the function were replaced with the low point so that the slope was equal to zero); and
    - Prevalence is constant after age 75.

An example calculation and graphical representation are presented below, for Diabetes prevalence in Wake County:

County Prevalence Data				**Regional Prevalence Data**				**Estimated Prevalence Data**	
Age Group	Prevalence	County Population	Individuals with Disease	Age Group	Prevalence	County Population	Individuals with Disease	Adjusted Number of individuals	Adjusted Prevalence
18-44	1.5%	386,848	**5,803**	18-24	0.4%	93,774	375	250	**0.3%**
				25-34	1.8%	140,898	2,536	1,693	**1.2%**
				35-44	3.8%	152,176	5,783	3,860	**2.5%**
						SUM:	***8,694***	**5,803 ✓**	
						ADJUSTMENT FACTOR:	***0.667***		
45+	10.7%	286,403	**30,645**	45-54	8.3%	133,472	11,078	8,745	**6.6%**
				55-64	17.6%	84,177	14,815	11,696	**13.9%**
				65+	18.8%	68,754	12,926	10,204	**14.8%**
						SUM:	***38,819***	**30,645 ✓**	
						ADJUSTMENT FACTOR:	***0.789***		



Population Disease Instance Estimation

Using a differential equation-based method developed by Ralph Brinks, age-specific incidence rates are derived for each study area population.[6] While this method is only applicable to chronic disease with no remission, the prevalence data on which incidence data are estimated are generally stated in the form of "Has your doctor every told you have [disease]?" or similar;[5] thus, the data available implicitly ignore the possibility of remission into a healthy state. While this may lead to overestimates of prevalence in the population for disease such as hypertension, it also ensures the validity of the incidence estimation procedure employed. To perform incidence rate estimations, the following steps were conducted for each study area (see Figure A1 for an example of this process):

1. Fit a second-order function, *s*(*a*) to given prevalence data
2. Take the derivative of the prevalence function, *ds*/*da*
3. Define the function *c*=((*ds*/*da*))/((1-*s*))
4. Estimate age-specific incidence using the following function; only used to predict incidence at ages for which prevalence is known $i(a)=c(a)+m(a)\times(1-(s(a)\times (R(a)-1)+1)^{-1})$
5. Fit a fourth-order function to the estimated incidence data between points. Assume incidence is zero below age 18 and constant above age 75.

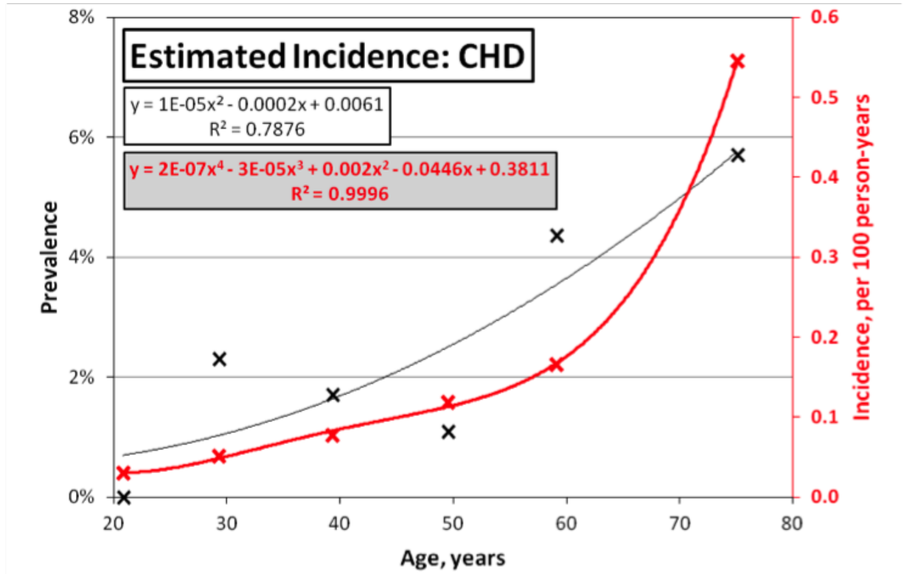


Figure A1. Estimated Incidence of CHD, Winterville Study Area

Transportation Behavior Estimation

We estimate increased physical activity from walking for transportation using behavioral evidence from studies of the built environment and transportation behavior. For the Winterville and BRRC study areas, we are interested in the total length and density of the sidewalk network because the plans we investigate include the construction of new sidewalks. In the Sparta study area, we are interested in the quality of the pedestrian environment because the Downtown Streetscape Strategy includes pedestrian improvements but no new sidewalk construction.

Considering sidewalk length and density, we focus on a dissertation exploring transportation behavior in the Raleigh-Durham-Chapel Hill Metropolitan Statistical Area completed by Yingling Fan, now an assistant professor at the University of Minnesota. The study considers transportation from three different perspectives and develops several predictive models linking built environment variables to transportation behaviors. Specifically, the study estimates that a 1% increase in total sidewalk length is associated with a 0.12% increase in average walking time. The study also estimates that a 1 mile per square mile increase in sidewalk density increases the odds of an individual having reported walking by 1.4%. We consider these two effects to be distinct effects that influence two different populations: average walking time influencing existing walkers and increases in the odds of walking influencing existing non-walkers. We estimate that the average increase in walking time applies evenly to each walking time category; thus, we multiply the average walking time of each walking time category by the predicted change and hold the percentage of the population in each walking time category constant. We then calculate the observed odds of walking, apply the predicted increase in odds, and multiply the total number of walkers by a factor so that the new odds equal the predicted increased odds. We assume that new walkers are distributed proportionally across all walking time categories based on the existing distribution. Conceptually, we increase the mean walking time of each walking time category ("expanding" each walking time category) using changes in total sidewalk length and move a portion of non-walkers into the walking time categories using changes in sidewalk density.

Considering improvements to sidewalk quality, we use the concept of a Pedestrian Environment Factor (PEF) first developed in the LUTRAQ project in Portland, Oregon. The PEF is a 12-point index that assesses the quality of the pedestrian environment based on four variables: 1) sidewalk quality; 2) ease of street crossings; 3) topography; and 4) local street network configuration. Each characteristic is assessed on a 3-point scale (1, 2, or 3) and the values are summed to derive the PEF; thus, the PEF can range from 4-12. As applied in research, PEF scores are divided into thirds; thus, the absolute PEF value in a given geography is less important that the relative value of the PEF compared to other geographies in the study area. For our purposes, we assume that topography and local street network characteristics remain constant pre- and post-project; however, both sidewalk quality and ease of street crossings increase in a subjective rating from 1 to 3. This results in a predicted increase in PEF of 4 points for the areas in the vicinity of the downtown streetscape improvements. We conservatively assume that this is analogous to a move from the lowest PEF third to the middle PEF third. Using a study by Boarnet et al. from 2008, we thus assume that this results in an increase of 0.71 miles per week per person living in the vicinity of the downtown streetscape project. We translate this value into a 13.6 minute increase in minutes walked per person per week living within 0.25 miles of the streetscape improvements and apply this increased walking time to both existing walkers and to non-walkers. Using GIS, we calculate that 25% of the total land area of the Town of Sparta is within 0.25 miles of the proposed improvements, thus we assume that only 25% of the population in each walking time category increases his or her walking time by this amount per week.

Appendix 4: DYNAMO-HIA Technical Documentation

DYNAMO-HIA Data Requirements

	Data	Source
Population	**Newborns:** *number of projected newborns for the given population*	*Unidentified*
	Overall DALY Weights: *percentage of disability*	*National Surveys*
	Overall Mortality: *observed mortality rate by age and sex*	*NC SCHS*
	Size: *population size by age and sex*	*Census/ACS*
Diseases	**Excess Mortality:** *additional mortality when having the disease*	*Epidemiological studies*
	Incidence: *number of cases per person-years, by age and sex*	*NC SCHS*
	Prevalence: *age and sex specific prevalence of the population*	*NC SCHS*
	Relative Risks from Diseases: *relative risk of contracting the disease when having another disease, by age and sex*	*Epidemiological studies*
	Relative Risks from Risk Factor: *Information on how the underlying risk factor affects the risk of contracting the given disease; differs slightly based on risk factor*	*Epidemiological studies*
	DALY Weights: *percentage of disability caused by disease*	*Unidentified*
Risk Factors	**Prevalance Data for Lack of Physical Activity:** *percentage in each exposure category for each age and gender (e.g., percent of population that is physically inactive*	*BRFSS or local surveys*
	Relative Risk for Death (optional): *relvative risk of the risk factor on total mortality; age and sex specific*	*Epidemiological studies*
	Relative Risk for Disability (optional): *relative risk of the risk factor on total disability; age and sex specific*	*Epidemiological studies*
	Transitions: *age and sex specific probability of switching from one risk factor category to another (key model component for our purposes)*	*Elasticities from literature on behavioral change due to changes in the built environment*

Data Preparation

For inclusion in the DYNAMO-HIA model architecture, data must be converted into .xml files with specific structures, depending on the type of data. This is accomplished using Excel Macros provided to the user during the DYNAMO-HIA model installation. Model files are entered into a folder with the following form: