# Executive Summary

## Project Background

EPA's Sustainable and Healthy Communities Research Program (SHC) is conducting transdisciplinary research to inform and empower decision-makers. EPA tools and approaches are being developed to enable communities to effectively weigh and integrate human health, socioeconomic, environmental, and ecological factors into their decisions to promote community sustainability. To help achieve this goal, EPA researchers have developed systems approaches to account for the linkages among resources, assets, and outcomes managed by a community. System dynamics (SD) is a member of the family of systems approaches and provides a framework for dynamic modeling that can assist with assessing and understanding complex issues across multiple dimensions. To test the utility of such tools when applied to a real-world situation, the EPA has developed a prototype SD model for community sustainability using the proposed Durham-Orange Light Rail Project (D-O LRP) as a case study.

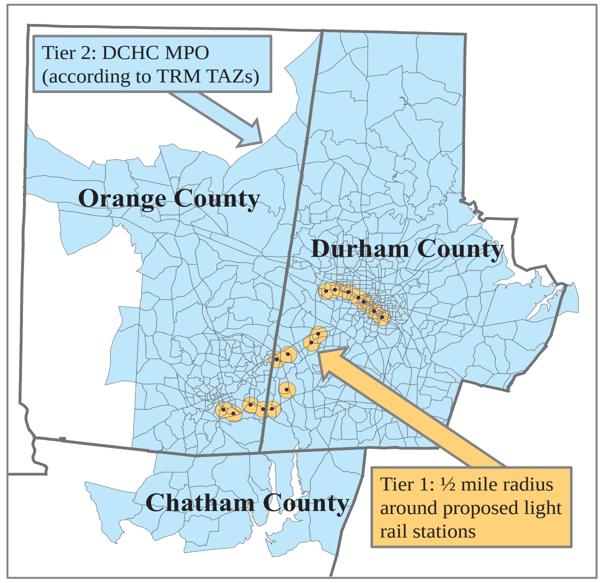
The EPA D-O LRP SD modeling team chose the proposed D-O LRP to demonstrate that an integrated modeling approach could represent the multitude of related cross-sectoral decisions that would be made and the cascading impacts that could result from a light rail transit system connecting Durham and Chapel Hill, NC. In keeping with the SHC vision described above, the proposal for the light rail is a starting point solution for the more intractable problems of population growth, unsustainable land use, environmental degradation, and the persistence of economic, social, and health inequities. To achieve the maximum potential benefits from the light rail across all of the dimensions of sustainability while reducing its potential negative consequences, concurrent policies must be weighed in combination with the light rail to assess the tradeoffs associated with these decisions. Therefore, the D-O LRP SD modeling team developed many concurrent policy scenarios in addition to the light rail that can aid stakeholders in finding leverage points within the system where interventions can have the largest impact.

In the first phase of this modeling effort, a conceptual model for the D-O LRP was designed with a high degree of input from stakeholders, including representatives from the regional transit authority, county health department, stormwater management department, and city and regional land use and transportation planning departments, among others. This conceptual model served as a framework for the operational SD model, which was built to evaluate a number of policy scenarios, many of which were also suggested by stakeholders. The operational model was subjected to rigorous quality assurance tests, including the sensitivity of the model to assumptions and inputs, and the evaluation of outcomes – social, economic, and environmental – resulting from actions that emanate from or impinge on the D-O LRP.

## Model Structure

The D-O LRP SD Model was calibrated using historical data and local projections, when available, for its two geographic boundaries: Tier 2 - the area defined as being within the boundaries of the Durham-Chapel Hill-Carrboro Metropolitan Planning Organization (DCHC MPO); and Tier 1 - the combined area of ½-mile-radius zones surrounding each of the proposed light rail stations (½-mile radius was chosen because it is common practice among urban planners to regard a half mile as the greatest distance that most people are willing to walk to a public transit station).

**Figure ES-1. Map of the D-O LRP SD Model Geographic Tiers**




Model variable outputs are reported for each Tier annually between 2000 and 2040. The model is designed to explore dynamic interactions among sectors of the urban system, including land use, transportation, energy, economics, equity, water, and health. These sectors are visualized in Figure ES-2, with plus (+) signs indicating a positive association between variables (an increase in A produces an increase in B, and a decrease in B produces a decrease in B), and minus (-) signs indicating a negative association between variables (an increase in A produces a decrease in B, and vice versa). Model scenarios run in a few seconds, and users can edit inputs or equations for any variable in the model.

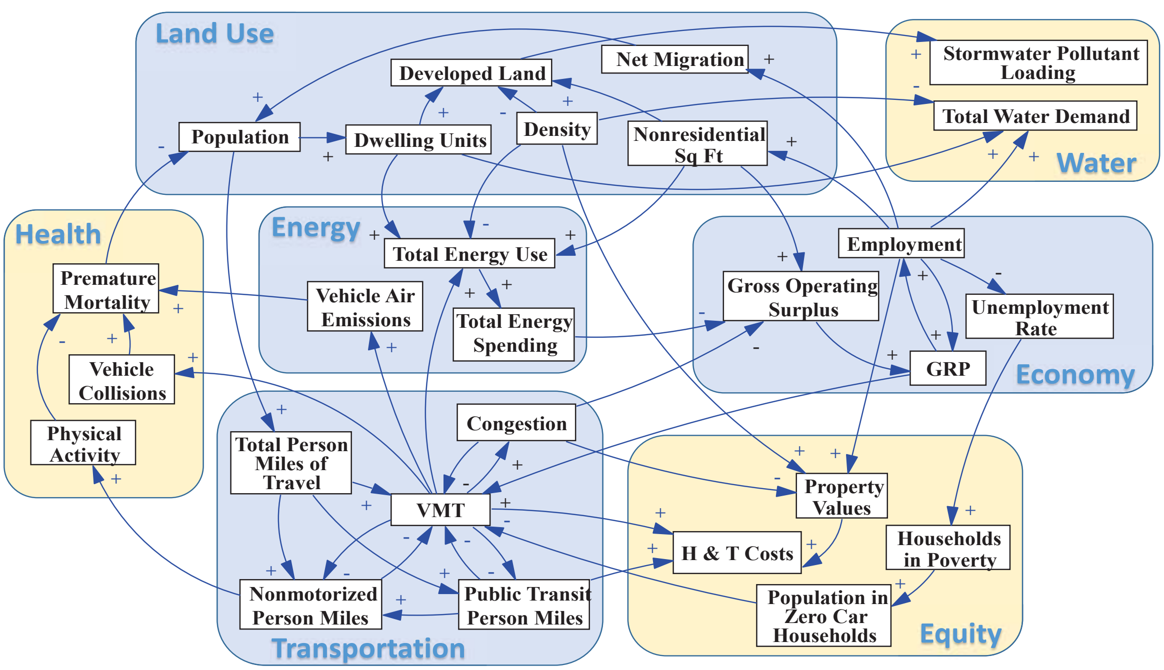



**Figure ES-2. Causal Loop Diagram (CLD) for the D-O LRP SD Model**

## Model Scenarios

Three main scenarios were run in the D-O LRP SD Model to reflect the most likely transportation and land use plans.

**1. Business-As-Usual BAU scenario**
The BAU scenario represents expected results if current demographic, land use, and transportation trends continue and serves as a baseline to contrast with the other scenarios described below.

**2. Light Rail scenario**
The Light Rail scenario represents the implementation of the 17-mile light rail transit (LRT) line by 2026 between Durham and Chapel Hill and also deviates from the BAU scenario as follows:

- Assumes LRT motivates more people to use public transit than an equal number of bus service miles;
- Assumes a 10% increase in demand for developed nonresidential (excluding industrial) floor space in Tier 1, gradually phased in during the six-year period of light rail construction; and
- Assumes a higher share of Tier 1 employees will choose to move to Tier 1 rather than commute from elsewhere in Tier 2.

**3. Light Rail + Redevelopment scenario**
The Light Rail + Redevelopment scenario represents the implementation of the LRT line with additional changes to zoning to encourage land redevelopment and increased density around the station areas.

- Assumes 20% of developed land is redeveloped to almost three times its existing density by 2040, starting in 2020 in anticipation of the rail

## Testable Interventions

The results of 17 additional policy, demographic, and market scenarios, were also analyzed to demonstrate the breadth of policies and other factors that can be tested with the model. Some of the main policy, demographic, and market levers that can be modified by users include:

- Policy Interventions
  - Density and redevelopment
  - Fare free transit
  - Parking price changes
  - Sidewalk building
  - Clean Power Plan
  - Stormwater management
- Demographic and Market Shifts
  - More multifamily households
  - Higher gas prices
  - Change in wages
- Technology Changes
  - Building energy efficiency
  - Vehicle fuel efficiency
  - Solar capacity

## Main Findings

### Findings from Model Construction

**The model uses defensible explanatory mechanisms to approximate historical trends.** We used documented causal relationships between variables to drive behavior in the model. After calibration, these mechanisms were adequate to reproduce historical trends, and they form the basis of future projections. While each variable in the model can potentially influence most other variables, Table ES-1 represents a select set of variables whose values are of high interest to decision makers (labeled "Indicators") and the set of additional variables (labeled "Drivers") that influence them most strongly in the model.

**Table ES-1. A Selection of Model Indicators and their Drivers**

| Indicator | Model Drivers |
|---|---|
| ***Economic*** | |
| GRP | Earnings, nonresidential sq ft, gross operating surplus per sq ft, energy spending, congestion |
| Employment | Labor force, GRP, retail consumption |
| Productivity loss due to congestion | VMT, congestion, per capita earnings |
| Nonresidential property values | Employment growth, retail density, building size |
| Residential Property values | Land availability, income growth, commute time, population growth, lot size, retail density |
| ***Social*** | |
| Poverty rate | Unemployment rate |
| Transit-dependent population | Population in poverty |
| Affordability index | Renter costs, vehicle costs, transit costs |
| Net premature mortalities avoided | VMT, $NO_x$ and $PM_{2.5}$ emissions per VMT, accidents per VMT, person miles of nonmotorized travel |
| Person miles of public transit travel | GRP, population, fare price, revenue miles, price of gasoline, MPG, traffic congestion, travel by other modes |
| Person miles of nonmotorized travel | GRP, population, nonmotorized travel facilities, jobs-housing balance, price of gasoline, MPG, traffic congestion, travel by other modes |
| ***Environmental*** | |
| Energy use | Building stock, building energy intensity, VMT, MPG |
| $CO_2$ emissions | Energy use, emissions intensity of electricity generation, solar capacity |
| Stormwater N and P loading | Developed land, impervious surface, stormwater mitigation (e.g. rain gardens) |
| VMT | GRP, population, population in zero-car households, price of gasoline, MPG, traffic congestion, travel by other modes |
| $PM_{2.5}$ and $NO_x$ emissions | VMT, emissions per VMT |

**The model has facilitated interactions among diverse stakeholders to address complex, interconnected community issues.** The CLD was developed based on the input of a diverse group of stakeholders, including local land use and transportation planners, sustainability experts, and public health leaders. This stakeholder group also provided feedback on preliminary model capabilities and results, which drove revisions and additions to the model.

## Selected Scenario Results

### *Economic*

**Job growth in Tier 1 due to the light rail is accompanied by greater traffic congestion despite decreases in per capita vehicle miles traveled (VMT).** When the light rail opens in 2026, there is a shift towards more transit use, decreasing VMT per capita by residents of Tier 1, as shown in Figure ES-3A. However, the D-O LRP SD Model assumes the light rail will increase demand for nonresidential floor space in the station areas, which leads to more employment growth between 2020 and 2040 than the BAU scenario (53% vs. 35%, Figure ES-4). This economic growth spurs population growth by encouraging immigration to the area and leads to increases in total VMT and congestion in Tier 1. Congestion sharply declines in 2026 due to the introduction of the light rail line (Figure ES-3B); however this decline is offset within four years by the increased traffic due to economic and population growth.

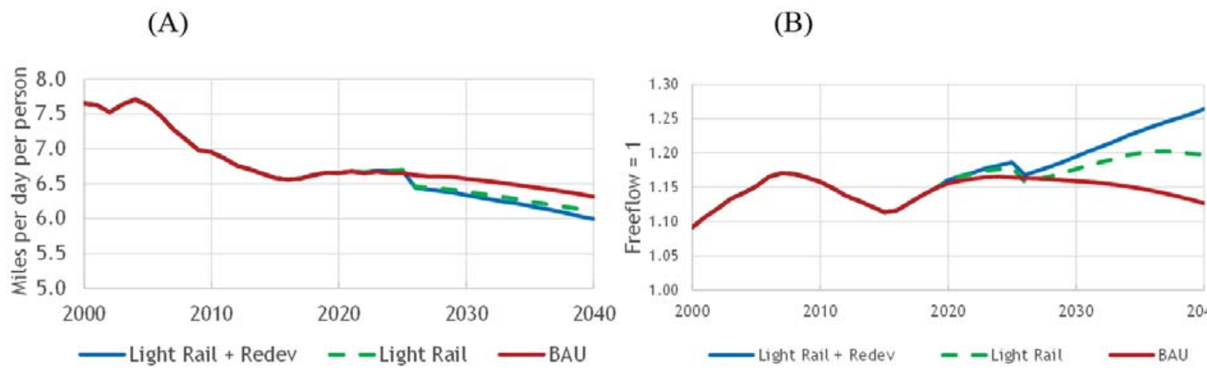



**Figure ES- 3. Light Rail Scenarios Compared to BAU for: (A) VMT by Tier 1 Residents per Day per Capita, and (B) Tier 1 Congestion**

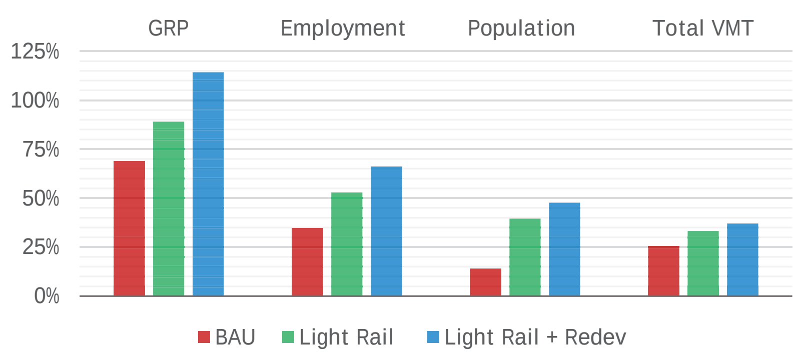



**Figure ES- 4. Change in Tier 1 Overall Growth Indicators Between 2020 and 2040**

**More of the potential economic benefits of light rail are realized in the Light Rail + Redevelopment scenario, due to compact redevelopment in Tier 1**. Denser development allows demand for nonresidential square feet to be met, causing gross regional product (GRP) to grow by 114% between 2020 and 2040, compared to only 89% under Light Rail alone (Figure ES-4).

### *Social*

**Compact redevelopment increases nonresidential property values far more than residential property values in Tier 1,** providing a win-win for tax revenues and housing affordability. In real terms, residential property values in the Light Rail + Redevelopment scenario are no more than 7% higher than BAU in 2040, while nonresidential property values increase by 136% more than under the Light Rail scenario in Tier 1 between 2020 and 2040 (Figure ES-5A). The rise in multifamily property values, coupled with an increase in vehicle costs, drives decline in the affordability index of 4.8% by 2040 in the Light Rail + Redevelopment scenario relative to BAU (Figure ES-5B). However, the rise in nonresidential property values leads to $660M more in cumulative real property taxes (PT) levied between 2020 and 2040 than under the Light Rail scenario in Tier 1 alone (Figure ES-5A).

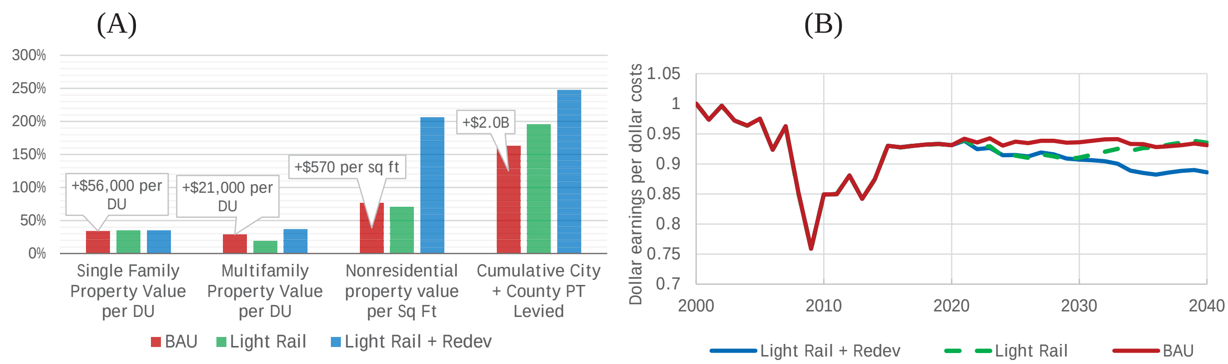



**Figure ES- 5. Tier 1 (A) Change in Single Family, Multifamily, and Nonresidential Property Values between 2020 and 2040 in Tier 1, (B) Affordability Index: Main Policy Scenarios Compared to BAU**

**Residents' health improves due to more walking and cycling under the light rail scenarios.** Within the context of an overall declining trend in nonmotorized travel per capita, the light rail encourages more walking and cycling relative to BAU (Figure ES-6A). Consequently, premature mortalities avoided due to an active lifestyle increase, resulting in 46 (Light Rail) and 54 (Light Rail + Redevelopment) cumulative additional avoided premature mortalities (Figure ES-6B). This net health improvement reflects that the benefits of increased physical activity outweigh the negligible impacts of increased $PM_{2.5}$ and $NO_x$ vehicle emissions and the slight increase in vehicle crash fatalities.

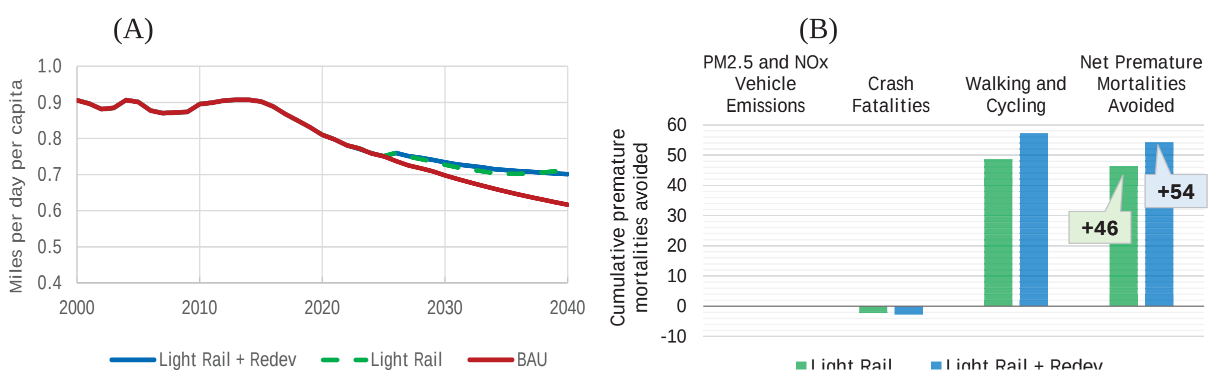



**Figure ES- 6. Health Effects in Tier 1: (A) Nonmotorized Travel by Residents per Day per Capita and (B) Cumulative Premature Mortalities Avoided by Cause and Net Cumulative Premature Mortalities Avoided between 2020 and 2040 for the Light Rail Scenarios: Departure from BAU**

*Environmental*

**Intensity indicators demonstrate improvements in resource use efficiency under the Light Rail + Redevelopment scenario in Tier 1 despite economic growth.** In 2040, impervious surfaces per capita in Tier 1 are 19% lower in the Light Rail + Redevelopment scenario than in BAU (Table ES-2). Daily water demand per capita in Tier 1 is also improved in the Light Rail + Redevelopment scenario, at 1.8% lower than BAU. On the other hand, $CO_2$ emissions per dollar of GRP increase in the Light Rail + Redevelopment scenario by 3% relative to the BAU. This is due to redevelopment increasing nonresidential use, which is more energy intensive than residential use.

**Table ES-2. Selected environmental intensity measures across the BAU, Light Rail, and Light Rail + Redevelopment scenarios**

| Tier 1 | BAU | Light Rail | | Light Rail + Redev | |
|---|---|---|---|---|---|
| | 2040 Value | 2040 Value | % diff from BAU | 2040 Value | % diff from BAU |
| Intensity Measures | | | | | |
| Impervious surface (acres) per capita | 0.08 | 0.068 | -12% | 0.062 | -19% |
| CO2 Emissions per GRP (tons/million USD 2010) | 94 | 93 | -1% | 97 | 3% |
| Daily water demand (Mgal/year) per capita | 0.050 | 0.048 | -4.1% | 0.049 | -1.8% |

**Determining the cumulative environmental impacts of scenarios requires viewing model results as a time series.** Although Light Rail and Light Rail + Redevelopment would appear to have the same impact on $CO_2$ emissions by 2030 (Fig ES-7A), they diverge afterward, leading Light Rail + Redevelopment to have the highest cumulative $CO_2$ emissions by 2040. The situation is opposite for stormwater N load (Fig ES-7B): although the two light rail scenarios have similar stormwater N load in 2040, Light Rail sustains this load for a longer time, so its cumulative stormwater N load is higher than Light Rail + Redevelopment by 2040.

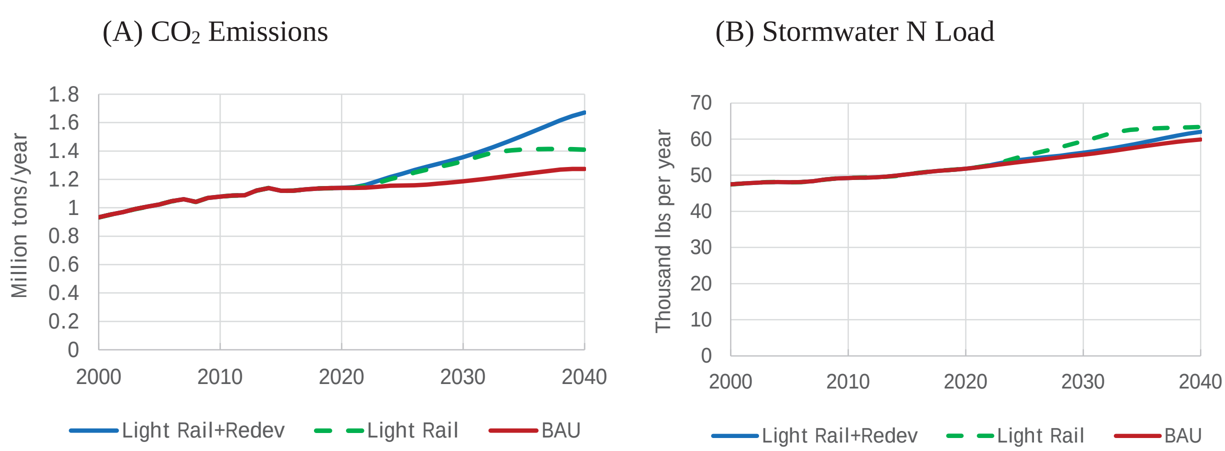



**Figure ES- 7. Environmental impacts in Tier 1: Light Rail, Light Rail + Redevelopment Scenarios Compared to BAU**

**Compact redevelopment increases energy use and $CO_2$ emissions intensity in Tier 1, due to unlocking growth potential and increasing nonresidential uses.** $CO_2$ emissions reductions strategies and stormwater management policies such as the Durham GHG Plan, the Clean Power Plan, and the Jordan/Falls Lake Rules can help offset the environmental impacts of growth described above. If applied to our model, emissions goals set by the Clean Power Plan would drop Tier 1 emissions by 16% from their projected 2030 level (Figure ES-8A). A stormwater N mitigation plan that would treat 30% of the stormwater N load from development after 2015 and 15% of the load from development existing before 2015 could cause stormwater N load to level off in Tier 1 (light blue line in Figure ES-8B).

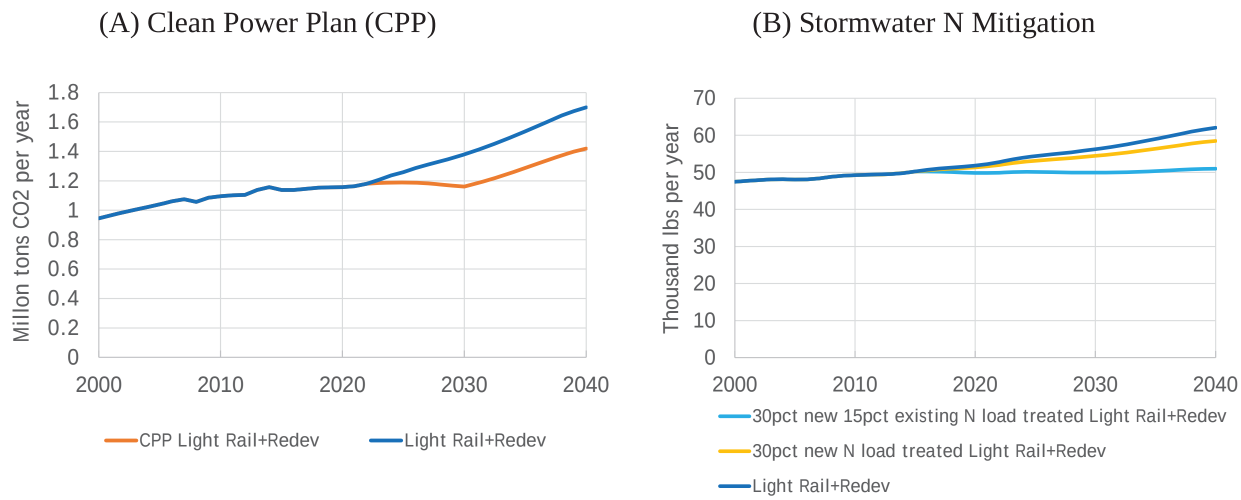



**Figure ES- 8. Mitigating the Environmental Effects of Light Rail + Redevelopment in Tier 1**

**Regional impacts of the light rail are quantified by the D-O LRP SD Model, but those impacts are less pronounced than in the station areas.** In terms of population, energy use, and water demand, Tier 2 is between seven and eleven times the scale of Tier 1. Therefore, the cascading impacts of the light rail are diluted in Tier 2. For example, projected annual energy use in 2040 is 10% higher in the Light Rail scenario compared to BAU in Tier 1, but only 3.9% higher than BAU in Tier 2. Similarly, nonmotorized travel by residents per capita is 15% higher in the Light Rail scenario than BAU in 2040 in Tier 1, but only 1% higher in Tier 2.

## Limitations of the Model

**The D-O LRP SD Model illustrates trends and relative magnitude, not predictions.** System dynamics models are intended to explore the complexity and interactions within a system, rather than produce an exact answer to a given question. Although our model explores policies and scenarios related to the role of light rail transit in sustainable regional development, our model does not provide specific directions to urban planners. Rather, it shows potential future trends, relative magnitudes of impact, and interactions among different sectors of the urban system.

**The model is not designed to work under extreme conditions or past the year 2040**. Model results have been extensively tested for inputs within reasonable value ranges, and model parameters have been set to work within these boundaries. Extreme values, changes to historical inputs, or extrapolation of results past the model timespan could produce unrealistic outputs.

**The model is not spatially explicit.** All inputs and indicators are aggregated to the level of the two modeled tiers.

## Intended Community Value

The system dynamics modeling approach can add value to three types of community processes:

1) **Regulatory process –** applying a multisector SD model like the D-O LRP model could allow the Indirect and Cumulative Impacts section of an Environmental Impact Statement (EIS) to have more quantitative projections. Currently the Indirect and Cumulative Impacts of the D-O LRP EIS are described as general increases or decreases. Applying a SD model would allow the regulatory process to consider the relative size of increases or decreases, so that tradeoffs could be weighed.

2) **Urban planners and planning process –** interactions between transportation, health and sustainability planners could be facilitated through a model that integrates their various sectors. In urban planning, actions in one department may compete with or counteract the interests of another department or agency. Developing and using a stakeholder-invested model could help departments to coordinate their efforts, or at least visualize how the actions of one department influence the interests of other departments.

3) **Public discussion –** an SD model can help explore issues that citizens raise at public meetings. A large-scale public project such as light rail transit requires an education and outreach effort to maintain public support. An SD model like the D-O LRP model can help citizens visualize the various ways in which a project like light rail transit can affect regional development.

## Next Steps

- **Model Version 2.0.** An updated version of the model is currently under development. It will include, an updated calibration of employment for the BAU scenario in Tier 1, updated estimates of the elasticities of person miles (by each mode of transportation) to GRP per capita, and additional model enhancements pending our interactions with stakeholders.

- **User Interface**. A more user-friendly interface will be developed to allow stakeholders to test assumptions and policy interventions, access relevant background information, and view indicators for side-by-side comparison.

- **Transferable Tools.** Ultimately, the experiences gleaned from this and other ORD and regional efforts to employ systems approaches will be consolidated into tools and guidance for communities and regions to apply these methods to a wide range of sustainability issues.