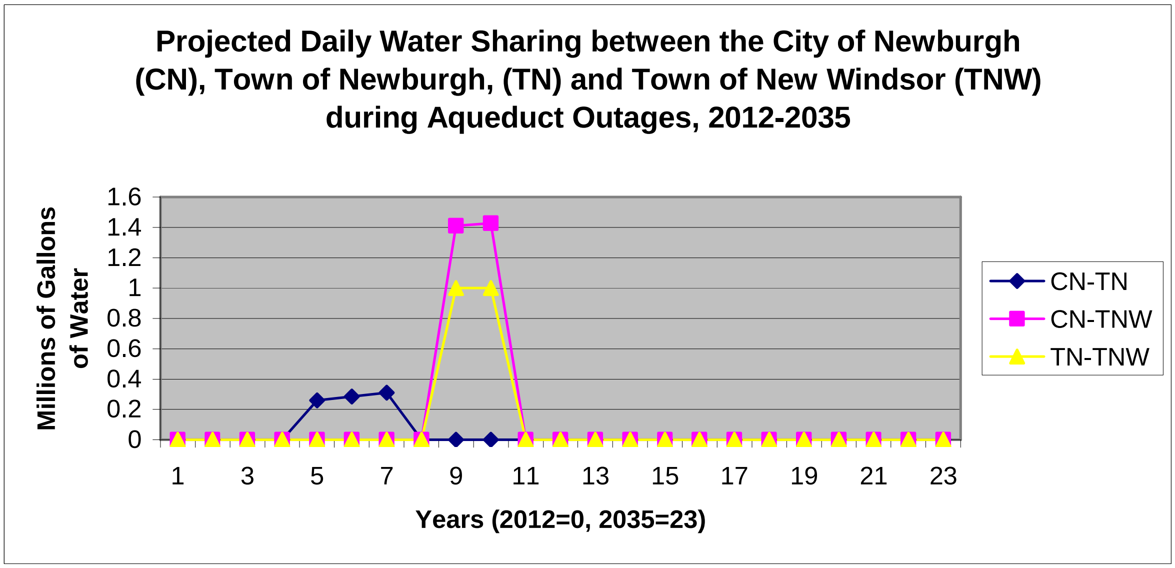
NEW YORK STATE
WATER RESOURCES INSTITUTE
Department of Earth and Atmospheric Sciences

1123 Bradfield Hall, Cornell University
Ithaca, NY 14853-1901
http://wri.eas.cornell.edu

Tel: (607) 255-3034
Fax: (607) 255-2016
Email: nyswri@cornell.edu

Further Development and Applications of a Planning Support System for Managing Change in Water Infrastructure Systems in Hudson River Municipalities

Kieran Donaghy,
kpd23@cornell.edu
w/Arash Beheshtian and Sara Davis
Department of City and Regional Planning
Cornell University, 106 W. Sibley Hall, Ithaca, NY 14853



Abstract

In this second stage of development of a prototype planning support system (PSS) for managing change in water infrastructure systems in Hudson River and Mohawk River communities, we have constructed a model that characterizes interdependencies and co-evolution of residential development, daily demands for water, daily draws of water from the Catskill and Delaware Aqueducts when the aqueducts are in service, and water sharing between communities when they are not in service. Our analysis is focused on the potential exigencies of the City of Newburgh, the Town of Newburgh, and the Town of New Windsor over the period of 2012-2035. The characterization of water sharing is predicated on implementation of infrastructural improvements recommended by the Orange County Water Authority's *Northeast Orange County Water Supply Project Facility Plan* of 2014. The model, which complements the computable general equilibrium model and water and transportation network models developed in the first stage of PSS development, supports examination of the potential effects of smart-growth policy implementation and can be used to facilitate development of inter-municipal agreements.

Three Summary Points of Interest

- Based on population projections of the 2012 *Newburgh Area Transportation & Land Use Study* running out to 2035, the anticipated capacity expansion of the City of Newburgh's water infrastructure system would appear to be inadequate to provide for the water needs of Northeast Orange County municipalities in the event that there are service outages of the Catskill and Delaware Aqueducts.
- Demand for water would appear to be manageable in part through conservation measures and the implementation of appropriate water fee schedules.
- Smart-growth policies can influence development patterns but will need to be combined with conservation and demand management efforts and a more ambitious program of infrastructure replacement to accommodate water needs by 2035.

Keywords: Population growth, water sharing, smart growth, planning support system.

1. Introduction

Developing and successfully implementing comprehensive regional growth strategies requires coordinated envisioning and clear communication between municipalities and agencies at the local, regional, and state levels. It also requires a shared understanding of interdependencies between development processes and demands placed upon infrastructure systems. This is particularly true of large-scale infrastructure projects. In the research discussed in this report a modeling framework has been developed to promote understanding of interdependencies and co-evolution of residential development, daily demands for water, daily draws of water from the Catskill and Delaware aqueducts when the aqueducts are in service, and water sharing between communities when they are not in service for the City of Newburgh, the Town of Newburgh, and the Town of New Windsor over the period of 2012—2035.

Much technical analysis of the issues here considered has already been conducted by planning and engineering firms in cooperation with planning and government authorities; hence, our research will build on the findings of several recently published studies. Our report thus begins with a review of the Northeast Orange County (NEOC) Water Supply Project Facility Plan (April 2014) within the context of Orange County's Newburgh Area Transportation and Land Use Study. It is important to note from the outset that these studies, while complementary, are predicated on different assumptions about residential growth patterns. We will also review the mandatory smart growth principles advanced by the New York State (NYS) Smart Growth Public Infrastructure Policy Act of 2010 before going on to discuss the modeling framework this research contributes and its implementation in simulation exercises.

2. Overview of Source Documents

2.1 Newburgh Area Transportation & Land Use Study (May 2012). The Newburgh Area Transportation & Land Use Study (NATLUS) was prepared for the Orange County Transportation Council (OCTC) in May 2012. The Study Advisory Group consisted of nine municipalities located in NEOC as well as the Metropolitan Transportation Authority, NYS Department of Transportation, NYS Thruway Authority, and the Port Authority of New York and New Jersey. Eight firms served on the Consultant Team. The study was motivated by the Orange County Department of Planning's economic projections indicating that the NEOC region will add approximately 13,820 people and 16,500 jobs by 2035. (p.33)

The 130-page report describes local and regional trends in development, transportation, and socioeconomic movement which serve as the framework for the study. A discussion of existing regional conditions is followed by an extensive land use build-out and transportation corridor analysis. The report concludes with land use and transportation recommendations to help support long-term sustainable development in the Newburgh Area.

Regional growth projections detailed in the NATLUS can help frame analysis of the NEOC water sharing plan. The Newburgh Study Area consists of the City of Newburgh, the Towns of Newburgh, New Windsor, Montgomery, and Cornwall, and the Villages of Walden, Montgomery, Maybrook, and Cornwall-on-Hudson. The region remains predominantly rural with low housing densities, although areas of higher populations dot the region. The City of Newburgh has the highest population and serves 20% of the Study Area's residents while occupying only 3% of the Study Area's land. (p.25)

During the late 20th Century and early 21st Century, Orange County experienced rapid development due to the availability of affordable housing. Important transportation corridors in the Newburgh Area (I-84, I-87, and future I-86), the Metro-North Railroad, and Stewart International Airport allow easy access to the Newburgh Area and it remains an attractive region for future development. As a result, the region has an opportunity to shape future growth with strategies that protect current strengths and valued characteristics while enhancing economic vitality. (p.25)

In preparing future land use recommendations, the authors of the NATLUS took into consideration many documents including the OC Comprehensive Plan, OC Open Space Plan, OC Water Master Plan, and OC Design Manual. The authors also reviewed the comprehensive plans and development strategies under consideration by each municipality.

Future growth projections based on four models (Unconstrained Build-Out, Business-as-Usual Build-Out, Smart Growth A Build-Out, and Smart Growth B Build-Out) are summarized on p.66. The Unconstrained Build-Out model projects development capacity under current zoning policies without specific consideration for future demand for housing or commercial space. The Business-as-Usual model projects areas of future population growth and development under current zoning policies which occurs in relation to existing developments (this is the "auto-pilot" development model). Smart Growth A projects development and population growth when municipal goals, as expressed in their comprehensive plans, are taken into consideration. Smart Growth B incorporates adjustments made by the Study Team to the Smart Growth A plans, allowing for increased density in some areas and an overall coordinated Smart Growth approach. (p.62-63)

SUMMARY OF LOCAL GOALS AND KEY RECOMMENDATIONS:

City of Newburgh *(p.35-37, 120-122)* - The City of Newburgh (CNB) has recently experienced the least growth in the region, adding only 2.1% in population between 2000 and 2010. Past economic declines have left the City with a population experiencing extreme poverty, few public resources, and problems with crime. As a result, CNB has struggled to attract opportunities for economic development and healthy population growth.

However, the City is strategically located to take advantage of existing transportation corridors and has set forth targets and strategies in its comprehensive plan, *Plan-it-Newburgh*, to shape the City through growth and development. The City has started to redevelop the waterfront area and is pursuing a significant waterfront redevelopment effort proposed by the Leyland Alliance. CNB envisions a thriving and walkable community with access to improved public transit, a range of housing options, better schools, and an overall improved quality of life.

If Smart Growth B principles are incorporated into planning and development strategies, the City could maximize infill opportunities to create strong, mixed-used neighborhoods. Growth initiatives will need to be highly focused to capitalize on the City's potential. CNB could experience population growth (expressed in dwelling units (DU) (Chart 1)), of 32% between 2010 and 2035 versus the 10% growth projected under the Business-as-Usual model.

The City's water capacity in 2010 was twice the volume of average demand. Due to existing infrastructure, the City may be able to add housing capacity and redevelopment projects without enlarging the water infrastructure system[1].

Town of Newburgh *(p.37, 123-124)* - The Town of Newburgh (TNB) does not have a well-defined town center and zoning policies have resulted in significant residential sprawl. Several hamlets serve as focal points by providing amenities and thus support slightly higher population densities. The TNB Comprehensive Plan expresses the Town's desire to maintain a small-town character while incorporating smart design practices and encouraging public transit opportunities. Because the TNB expanded water and sewer infrastructure prior to 2012 and has large tracts of developable land, the area is prepared to accommodate new housing developments[2].

The Town faces some of the region's most intense growth pressures and has proposed zoning changes to protect agricultural lands and open space. The Town must be proactive to ensure development remains in line with stated hamlet-center strategies and smart growth objectives.

Recent growth has resulted in significant congestion on available roads. In order to encourage hamlet-centered growth objectives, the NATLUS authors recommend that development is prioritized to incentivize concentrated infrastructure construction, particularly when involving water and sewer line costs. A clear and defined comprehensive plan and firm leadership is necessary for TNB to control development and meet desired growth objectives.

By implementing Smart Growth B strategies, TNB would be able to temper growth pressures and achieve an 18% increase in dwelling units by 2035, as opposed to a 36% increase indicated by the Business-as-Usual model (Chart 1).

Town of New Windsor *(pp.46-47, 124-125)* - The Town of New Windsor (TNW) contains several hamlets which support some moderate density residential areas. However, many low density development opportunities exist due to available open land. The waterfront along the Hudson primarily supports industrial uses. The Town's strongest development magnets are Stewart International Airport and the Vail's Gate commercial area. However, TNW has some of the most congested transportation corridors in the region, creating significant challenges to residents and travelers.

The TNW must develop strategies to capitalize on economic development opportunities presented by Stewart Airport while maintaining desired landscape characteristics. Concentrated development will enable the Town to develop three or four focal centers for the area. This will help ensure that open space and agricultural lands remain protected. Successful development will include strategic transportation planning to facilitate smooth traffic flows. Poorly planned transportation corridors will result in increased congestion spurred by increased traffic.

In order to shape development based on smart growth principles and to increase the vibrancy of downtown New Windsor, the Town must encourage more mixed-use development. Under current, Business-as-Usual development, TNW is facing a 23% increase in dwelling units by 2035. By employing strategies from the Smart Growth B plan, TNW can limit the increase in dwelling units to 15%.

[1] This analysis by the NATLUS authors does not take into consideration the need for CNB to share its water supply with TNB and TNW.

[2] A map of the referenced water infrastructure was not available for this review, and it is not known whether these pipes are currently in use.

Municipality	Population Growth 2000-2010	2010 Existing Dwelling Units (DU)	2010 - 2035 DU Business-as-Usual	2010 - 2035 DU Smart Growth A	2010 - 2035 DU Smart Growth B
City of Newburgh	2.1%	12,397	10%	18%	32%
Town of Newburgh	8.1%	10,695	36%	24%	18%
Town of New Windsor	10.4%	9,655	23%	26%	15%

Chart 1: Projected population increase rate by 2035, based on dwelling unit count, for CNB, TNB, and TNW.

2.2 Northeast Orange County Water Supply Project Facility Plan (April 2014). The 328-page Northeast Orange County Water Supply Project Facility Plan provides a detailed strategy for the City and Newburgh, Town of Newburgh, and Town of New Windsor to implement a mandatory water sharing project in advance of a drastic change in water source supply to the region. The Plan was prepared by four consulting firms, led by HDR, for the Orange County Water Authority's NEOC Water Supply Project.

CNB currently acquires all water from its reservoirs of Washington Lake and Silver Stream Reservoir, with a backup connection to the NYC Catskill Aquaduct (CA). TNB receives most water from the NYC Delaware Aquaduct (DA), with additional water available from the Chadwick Lake. TNW receives all water from the CA, with some residents using well water. (p.15) NYC plans to shut down the CA for 10 months in 2016, and the DA for a longer period in 2021. (p.5) The CNB, as owner of the largest available local water supply, has been identified to provide water to the neighboring municipalities.

In order to recommend options for a reliable water sharing strategy, the authors projected future, short-term demand for water across the three municipalities based on water demand extrapolated from recent population growth rates: 2% for CNB, 8% for TNB, and 11% for TNW.(p.29)

The study also identified potential new sources of groundwater to supplement existing resources.

Municipality	Population Growth 2000-2010	Assumed Facility Plan Population Growth Rate	2012 Actual Water Customers	2016 Projected Water Customers	2021 Projected Water Customers
City of Newburgh	2.1%	2%	28,991	29,242	29,556
Town of Newburgh	8.1%	8%	24,133	24,944	25,958
Town of New Windsor	10.4%	11%	22,827	23,822	25,067
Total			75,951	78,008	80,581

Chart 2: Projected population growth of customers who will require access to municipal water supply through 2021.

Although the funding necessary to implement the Water Supply Facility Plan has not yet been identified, strategic planning and implementation of water infrastructure upgrades will help the involved parties potentially qualify for more affordable loans.

2.3 New York State Smart Growth Public Infrastructure Policy Act of 2010. The NYS Smart Growth Public Infrastructure Policy Act of 2010 charges all funding agencies to meet 10 specific smart growth guidelines. The incorporation of smart growth principles can directly impact how public grants and low-interest loans are awarded for public infrastructure projects.

The 10 guidelines, as summarized by Glenn Gidaly, are:

1. Use, maintain or improve existing water and sewer services
2. Locate public infrastructure within municipal centers
3. Promote development projects in developed areas or in areas identified for development in a comprehensive plan, local waterfront revitalization plan or brownfield redevelopment plan
4. Protect, preserve New York State resources
5. Foster mixed land uses and compact development
6. Provide for mobility through a variety of transportation choices
7. Coordinate between state and local governments
8. Promote community-based planning and collaboration
9. Ensure predictability in land use codes
10. Strengthen existing communities so as to reduce greenhouse gas emissions

2.4 Potentially Misaligned or Overlooked Objectives. For the research here reported, the Facility Plan's precise water supply volume and construction recommendations have not been rigorously studied against the various Build-Out models presented in the NATLUS. However, it appears that a review is warranted to ensure that the CNB will have the water capacity needed to support new population growth, while the TNB and TNW should ensure that any water infrastructure build-out supports their objectives to shape development in line with sustainable growth approaches. The Water Supply Project Facility Plan based future regional growth projections on the approximate growth pattern from 2000 to 2010, allowing for 2% growth for CNB, 8% for TNB, and 11% for TNW.

It seems reasonable to ask what the intended lifecycle of the proposed Facility Plan is, and how NEOC and the three municipalities should approach and execute the mandatory water infrastructure upgrades. In order to answer this question, a review of population growth predictions is necessary.

In 2012, 75,951 customers were served by municipal water services. Some residents currently get water from individual wells and they are not included in the customer count. Extrapolated out to 2035, the Facility Plan's proposed infrastructure may support a total population of approximately 88,221 residents[3]. However, the Orange County Department of Planning estimates that the CNB, TNB, and TNW will together be home to over 94,000 residents, regardless of whether the build-out model utilized is Business-as-Usual, Smart Growth A, or Smart Growth B. (Chart 3)

[3] Long-term (2035) capacity of the Facility Plan has not been calculated yet for this assessment.

Municipality	Actual Water Customers in 2012	Facility Plan Projected Population in 2035	Business-as-Usual Projected Population in 2035*	Smart Growth A Projected Population in 2035*	Smart Growth B Projected Population in 2035*
City of Newburgh	28,991	30,343	32,046	34,377	38,455
Town of Newburgh	24,133	28,824	34,181	31,165	29,657
Town of New Windsor	22,827	29,053	27,908	28,588	26,093
Total	75,951	88,221	94,135	94,131	94,205

* based on Dwelling Unit occupancy of 2.35 individuals, calculated from Chart 1 figures.

Chart 3: 2035 population forecasts extrapolated from data presented in Chart 1 and Chart 2.

2.5 Preliminary Conclusion and Recommendations. On the basis of the extant studies and legislation reviewed, several preliminary observations can be made. In order to most effectively comply with Orange County guidance to meet local water demand in the absence of NYC aqueduct-supplied water, and to accomplish this in line with a coordinated Smart Growth approach that will provide maximum long-term benefit to all parties involved:

- CNB should calculate potential municipal demands under higher growth projections in line with the NATLUS. Achieving higher growth will be a long-range process, but CNB can use this opportunity to lay the groundwork to plan for a possible increase in water demand from within the City.
- TNB should calculate potential municipal demands under lower growth projections in line with the NATLUS. Growth projections should be aligned with current and planned development projects. TNB should strive to strategically shape development zoning policies to facilitate a coordinated improvement in transportation and water infrastructure.
- TNW should calculate potential municipal demands under lower growth projections in line with the NATLUS. Growth projections should be aligned with current and planned development projects. TNW should strive to strategically shape development zoning policies to facilitate a coordinated improvement in transportation and water infrastructure.
- The three municipalities should candidly discuss short-term and long-term water sharing expectations in conjunction with broader regional development including transportation and land-use implications.

Development and implementation of a modeling framework that can begin to support conversations about residential development, water needs, and water sharing is now presented.[4]

3. Simulation Modeling

3.1 Equations of the Model. The basic model constructed in this stage of PSS development comprises five blocs of equations, which determine simultaneously the numbers of households in single-family and multiple-unit dwellings in each of the three municipalities, the numbers of housing-units of each type of housing in each community, the (normalized) sale prices of single-family homes and rents of apartments in multiple-unit dwellings, the daily demands for water in each municipaliaty, and daily draws from aqueducts by municipalities when the aqueducts are in service and

[4] We say 'begin' to support conversations because information about financing of infrastructural improvements, life-cycle operation and maintenance, and allocations of user fees is presently not available.

water sharing between municipalities when the aqueducts are out of service. Model specification is predicated on the assumption that the recommendations of the Orange County Water Authority's Facility Plan will be implemented. A description of the equations in each bloc follows.

Households. As noted above, the NATLUS projects substantial growth in population for the Newburgh area over the period from 2012 to 2035. We assume, as the study does, that population levels can be converted to households at the rate of 2.35 people per household. We also assume that the division in households residing in single-family and multiple-unit dwellings will continue to hold over the period of projection. In distributing the annual growth in the numbers of households of both types projected by the NATLUS in a straight-line fashion—i.e., such that increments of households residing in single-family and multi-unit dwellings in the Newburgh area are constant each year—the challenge is to allocate households of both types to Newburgh-area municipalities.[5] A mechanism for doing so is provided by a so-called 'gravity model' of spatial interaction. In the case of households seeking to rent multiple-unit housing, the mechanism is defined by:

$$m_{ijt}^{mu} = \frac{COL_{jt}^{-\beta_0}(P_{jt}^{mu})^{-\beta_1}(1-HOR_{jt})ACC_{jt}}{\sum_j COL_{jt}^{-\beta_0}(P_{jt}^{mu})^{-\beta_1}(1-HOR_{jt})ACC_{jt}}, \text{ for } j=1,2,3. \tag{1}$$

In equation (1) m_{ijt}^{mu} is a time-varying coefficient that allocates to municipality *j* in year *t* a share of the annual increment of households seeking rental housing in the Newburgh area from source *i,* where *i* in this case encompasses all possible sources.[6] The expression in the numerator of (1) contains terms reflecting both sources of attraction to and sources of repulsion from a municipality.

COL_{jt} = normalized cost of living in municipality *j* in year *t*.

P_{jt}^{mu} = normalized rental price of an apartment in a multiple-family housing unit in community *j* in year *t*.

HOR_{jt} = home-ownership ratio in municipality *j* in year *t.*

ACC_{jt} = an index of transportation accessibility in municipality *j* in year *t*.

We will assume that renting households will seek housing in areas where multiple-unit housing is more prevalent, hence $(1-HOR_{jt})$ reflects a measure of attractiveness to such households. The coefficient m_{ijt}^{mu} indicates the attractiveness of community *j* for renters relative to all potential municipalities. In equation (1), β_0 is a cost-of-living elasticity of demand for residence in municipality, whereas β_1 is a price elasticity of demand for housing. We assume that these parameters are constant across the three municipalities and two housing types.

In the case of households seeking to purchase a single-family home, the relevant time varying allocative coefficient would be

$$m_{ijt}^{sf} = \frac{COL_{jt}^{-\beta_0}(P_{jt}^{sf})^{-\beta_1}HOR_{jt}\cdot ACC_{jt}}{\sum_j COL_{jt}^{-\beta_0}(P_{jt}^{sf})^{-\beta_1}HOR_{jt}\cdot ACC_{jt}}, \text{ for } j=1,2,3, \tag{2}$$

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[5] We have no information on which to base an assumption of how the growth of population is likely to be distributed, so we assume the distribution is straight-line.

[6] By convention, continuous-time variables are usually written as explicit functions of time—e.g., *x*(t)—and discrete-time variables are written with time-period subscripts—e.g., x_t. For convenience of exposition, we shall adopt the latter practice in the case of continuous-time variables.

where P_{jt}^{sf} is the normalized median price of a single-family home in municipality *j*.

Denoting by HH_{jt}^{mu} and HH_{jt}^{sf} the numbers of households occupying multiple-unit and single-family residences in community *j* in year *t*, changes in these quantities in the three municipalities in the Newburgh area are given by

$$DHH_{jt}^{mu} = m_{ijt}^{mu} \cdot \overline{DHH}^{muna}, \text{ for } j=1,2,3, \tag{3}$$

$$DHH_{jt}^{sf} = m_{ijt}^{sf} \cdot \overline{DHH}^{sfna}, \text{ for } j= 1,2,3, \tag{4}$$

where $\overline{DHH}^{muna}$ and $\overline{DHH}^{sfna}$ denote constant increments of households seeking multiple-unit and single-family housing units in the Newburgh area over the 2012-2035 period and *D=d/dt* is the differential operator. Differential equations (3) and (4) account for changes in demand for two broad categories of housing. We now need to account for behavior on the demand side of the market, housing supply.

Housing units. We model the changes in the stocks of both multiple-unit and single-family housing in equations (5) and (6) below as responses by developers/builders to two factors—the rental and sale prices of multiple-unit and single-family housing units in communities *j* at time *t*, P_{jt}^{mu} and P_{jt}^{sf}, and the numbers of units of each type permitted in the communities at that time, PU_{jt}^{mu} and PU_{jt}^{sf}. The latter quantities are assumed to be determined as a matter of policy by development authorities.

$$D\ln HU_{jt}^{mu} = \gamma_{1j}^{mu} \ln(\alpha_j^{mu} vra (P_{jt}^{mu})^{\beta_2} PU_{jt}^{mu} / HU_{jt}^{mu}), \text{ for } j=1,2,3, \text{ when } PU_{jt}^{mu} \geq HU_{jt}^{mu}, \text{ and is 0 otherwise,} \tag{5}$$

$$D\ln HU_{jt}^{sf} = \gamma_{1j}^{sf} \ln(\alpha_j^{sf} vra (P_{jt}^{sf})^{\beta_2} PU_{jt}^{sf} / HU_{jt}^{sf}), \text{ for } j=1,2,3, \text{ when } PU_{jt}^{sf} \geq HU_{jt}^{sf}, \text{ and is 0 otherwise.} \tag{6}$$

In equations (5) and (6), which are written in elasticity-of-response form and where γ_{1j}^{mu} and γ_{1j}^{sf} denote the elasticities of response, α_j^{mu} and α_j^{sf} are scaling parameters, β_2 denotes the price-elasticity of housing supply, *vra* denotes an adjustment by developers/builders for the desired vacancy rate of building stock, and *ln* denotes the natural logarithm operator. Each of these equations gives the percentage rate of change in the respective housing stock variable for municipality *j* as a first-order exponential lag adjustment of the number of housing units of the type in question to its partial-equilibrium supply level. Note that housing units of a particular type can increase *only* if the permitted number of units of that type is at least as large as the number of housing units.

Housing prices. The third bloc of equations, (7) and (8) below, represents adjustments in housing prices and rents. The specification we adopt is a generic 'excess demand' one, according to which prices and rents respond positively to excess demand for housing and negatively to excess supply. (We construe the numbers of households residing in or seeking housing of particular types in given communities to represent aggregate demand for housing of those types and the numbers of units of those housing types to represent aggregate supply.) Like equation (5) and (6), (7) and (8) are written in elasticity of response form, where γ_{2j}^{mu} and γ_{2j}^{sf} denote the elasticities of response. Each equation gives the percentage rate of change in the respective housing price or rent as a function of the percentage difference between housing demand and housing availability.

$$D\ln P_{jt}^{mu} = \gamma_{2j}^{mu} \ln(HH_{jt}^{mu} / HU_{jt}^{mu}), \text{ for } j=1,2,3, \tag{7}$$

$$D\ln P_{jt}^{sf} = \gamma_{2j}^{sf} \ln(HH_{jt}^{sf} / HU_{jt}^{sf}), \text{ for } j=1,2,3. \tag{8}$$

Daily water demand. The fourth bloc of equations, (9), estimates the daily demands for water in the three municipalities (yearly averages) in year *t*, W_{jt}^{d}. Daily water demand is calculated as the product of the average daily rate of water consumption per person in a municipality, gpp_j, the size of the municipality's population, (2.35 persons/HH * total number of HH), and a normalized price for water service inclusive of tax, $P_{jt}^{w} = 1 + Tax_{j}^{w}$, in which Tax_{j}^{w} is the tax on water use (or user fee) in community *j*. In (9), β_3 is the price-elasticity of demand for water, which we assume to be constant across municipalities.

$$W_{jt}^{d} = 2.35 \cdot (HH_{jt}^{mu} + HH_{jt}^{sf}) \cdot gpp_j \cdot (P^{w})^{-\beta_3}, \; j=1,2,3. \qquad (9)$$

Daily aqueduct draws and water sharing. The fifth bloc of equations, (10) – (15), characterizes daily draws of water from the Catskill and Delaware aqueducts when the aqueducts are in service and water sharing between municipalities when the aqueducts are out of service. Before specifying this bloc of equations it will be helpful to first define some additional notation. We define the following variables in terms of millions of gallons per day in year *t*:

A_{1t}^{c} = daily draw by the City of Newburgh from the Catskill Aqueduct,
A_{2t}^{d} = daily draw by the Town of Newburgh from the Delaware Aqueduct,
A_{3t}^{c} = daily draw by the Town of New Windsor from the Catskill Aqueduct,
Q_1 = daily capacity of the City of Newburgh to provide water (assumed fixed),
O_2 = daily capacity of the Town of Newburgh to provide water (assumed fixed),
O_3 = daily capacity of the Town of New Windsor to provide water (assumed fixed),
Z_{12t} = daily delivery of water to the Town of Newburgh by the City of Newburgh,
Z_{13t} = daily delivery of water to the Town of New Windsor by the City of Newburgh,
Z_{23t} = daily delivery of water to the Town of New Windsor by the Town of Newburgh.

The equations characterizing aqueduct draws and water sharing can now be written as:

$A_{1t}^{c} = W_{1t}^{d} + Z_{12t} - Q_1$, when $W_{1t}^{d} + Z_{12t} \geq Q_1$ and the Catskill Aqueduct is in service, and is 0 otherwise, (10)
$A_{2t}^{d} = W_{2t}^{d} - Q_2$, when the Delaware Aqueduct is in service and is zero otherwise, (11)
$A_{3t}^{C} = W_{3t}^{d} - Q_3$, when the Catskill Aqueduct is in service and is zero otherwise, (12)
$Z_{12t} = W_{2t}^{d} - Q_2$, when the Delaware Aqueduct is out of service and is zero otherwise, (13)
$Z_{13t} = W_{3t}^{d} - Q_3 - Z_{23t}$, when the Catskill Aqueduct is out of service and is zero otherwise, (14)
$Z_{23t} = 1.0$, when the Catskill Aqueduct is out of service and is zero otherwise. (15)

For given parameter settings, initial values of endogenous variables, and time paths of exogenous or policy variables, the five blocs of equations can be solved (integrated) numerically over the 23-year period considered in the NATLUS report.[7] The settings of parameters and constant terms employed in calibrating the model are as given in Table 1.

[7] Solution of the model is presently obtained by implementing Clifford Wymer's simulation program APREDIC, which employs a variable-order, variable-step Adams method of numerical integration.

Behavioral Parameters	*Constants*
$\gamma_{1j}^{mu} = \gamma_{1j}^{sf} = 0.67$, for all j	$\overline{DHH}^{muna} = 0.126$
$\gamma_{2j}^{mu} = \gamma_{2j}^{sf} = 1.0$, for all j	$\overline{DHH}^{sfna} = 0.138$
$\beta_0 = 1.0$	*vra* = 1.05
$\beta_1 = 0.75$	*pphh* = 2.35
$\beta_2 = 1.4$	$gpp_1 = 0.15867$
$\beta_3 = 0.51$	$gpp_2 = 0.13260$
$\alpha_j^{mu} = \alpha_j^{sf} = 1.02$ for all j	$gpp_3 = 0.13142$
	$Q_1 = 8.9$
	$Q_2 = 2.7$
	$Q_2 = 0.4$
	$ACC_1 = 5.0$
	$ACC_2 = 3.0$
	$ACC_3 = 2.0$
	$COL_1 = 0.95$
	$COL_2 = 1.00$
	$COL_3 = 1.43$

Table 1. Settings of Behavioral Parameters and Constant Terms Employed in Simulations

The elasticity of response parameter values reflect the assumptions that the adjustment in housing supply requires a period of a year and a half whereas housing prices respond fully within a year. Price elasticities of demand and supply are taken from the urban economics literature (Espy et al, 1997, Hanushek and Quigley, 1980, McDonald and McMillan, 2007). The values of the scaling parameters were selected to promote realization of normalized housing prices in equilibrium solutions. Among the constant terms, the accessibility and cost-of-living index values were chosen to reflect qualitative discussions in the NATLUS. (These can be modified to reflect alternative conditions or endogenized as functions of other developments characterized by the model. For example, accessibility could be endogenized as a function of transport services provided *and* congestion in thoroughfares, reflected in V/C ratios.)

We conduct six simulations with the model to demonstrate the nature of thought experiments/simulations it can be used to conduct. In these simulations, different combinations of smart-growth policy measures are implemented. These include changes in accessibility, rates of growth in permitted housing units, and taxes/user fees for water consumption. (Impact fees on developers could also be easily introduced in a more complete model reflecting costs of infrastructure construction and maintenance.) Again, we are assuming that the infrastructural improvements proposed in the OCWA Facility Plan are implemented.

The first three simulations reflect build-out scenarios considered in the NATLUS—'business as usual (BAU),' 'smart growth A (SGA),' and 'smart growth B (SGB).' The simulations differ most in the assumed rates of growth in permitted housing in the municipalities, where both multiple-unit and single-family dwellings are assumed to be permitted to increase at the same rate. In the fourth simulation, 'smart growth C (SGC),' rates of growth in permitted housing units are differentiated by municipality and housing type. The fifth simulation, 'No-Tax,' shares the assumptions of the fourth simulation, with the exception that the water tax is set to zero to illustrate how demand for water and water draws would be affected. The sixth simulation, 'ACC-Par,' assumes that policies have been implemented to make accessibility equal in all three municipalities to demonstrate the potential impact of a program of transportation improvements (or degradation to uniform levels of poor service). The operative rates of growth are presented in Table 2.

			Simulation			
	BAU	SGA	SGB	SGC	No-Tax	ACC-par
PU^{mu}_{1t}	0.004 (=0.4%)	0.0072	0.0128	0.012	0.012	0.012
PU^{sf}_{1t}	0.004	0.0072	0.0128	0.009	0.009	0.009
PU^{mu}_{2t}	0.0144	0.0096	0.0072	0.009	0.009	0.009
PU^{sf}_{2t}	0.0144	0.0096	0.0072	0.0045	0.0045	0.0045
PU^{mu}_{3t}	0.0092	0.0104	0.006	0.009	0.009	0.009
PU^{sf}_{3t}	0.0092	0.0104	0.006	0.0045	0.0045	0.0045

Table 2. Annual Rates of Growth in Permitted Housing Units by Simulation

Plots of the time paths of model variables for the ACC-Par simulation are provided in the appendix to this report to illustrate the behavior of the model. In Table 3 we present measures for the six simulations reflecting the state of residential development and water use at the end of the build-out period in 2035.

			Simulation			
Variable	BAU	SGA	SGB	SGC	No-Tax	ACC-Par
$HU^{mu}_{1,35}$	11,447	11,495	11,566	11,550	11,550	11,203
$HU^{sf}_{1,35}$	5,638	5,675	5,734	5,712	5,712	5,286
$HU^{mu}_{2,35}$	3,798	3,764	3,738	3,750	3,750	3,972
$HU^{sf}_{2,35}$	9,752	9,687	9,653	9,635	9,635	9,653
$HU^{mu}_{3,35}$	1,419	1,420	1,410	1,415	1,415	1,539
$HU^{sf}_{3,35}$	10,365	10,383	10,330	10,326	10,326	10,732
$W^{d}_{1,35}$ (in *mgd*)	5.135	5.148	5.168	5.163	5.786	4.926
$W^{d}_{2,35}$	3.374	3.360	3.350	3.352	3.756	3.414
$W^{d}_{3,35}$	2.912	2.914	2.907	2.910	3.260	3.045
$A^{c}_{1,35}$	0	0	0	0	0	0
$A^{c}_{3,35}$	2.512	2.514	2.507	2.510	2.860	2.645
$A^{d}_{2,35}$	0.674	0.660	0.650	0.652	1.056	0.714

Table 3. Measures Reflecting Residential Development and Water Use under Different Policies

4. Discussion of Results and Policy Implications

From the review of existing studies and the results of simulations based on behavioral and technological assumptions that comport well with the literatures of urban economics and planning conducted for this report, we can draw a number of inferences.

- The anticipated capacity expansion of the City of Newburgh's water infrastructure system and attendant improvements for water sharing would appear to be inadequate to provide for the water needs of growing

Northeast Orange County municipalities in the event that there are service outages of the Catskill and Delaware Aqueducts.

- Demand for water would appear to be manageable in part, however, through conservation measures and the implementation of appropriate water fee schedules. One anticipates that upgrading of infrastructure will also reduce wastage and inefficiencies of system operation.
- The simulations presented in Table 3 (above) demonstrate considerable variability in patterns of residential development and water use. They suggest that smart-growth policies can influence development patterns but will need to be combined with conservation and demand management efforts and a more ambitious program of infrastructure replacement to accommodate water needs by 2035. The simulations would also seem to indicate that the role of development authorities in steering residential development by location and housing type is particularly important but that differential levels of accessibility to transportation services needs to be addressed simultaneously. (This observation only reinforces conclusions reached in the NATLUS report.)

The characterizations of residential development and water demand presented in this report will be integrated with modeling components developed earlier and integrated into a more comprehensive planning support system (PSS) for use in Orange County. As more information becomes available on the financing of infrastructural improvements and possible cost sharing arrangements to be determined through intermunicipal agreements, greater realism can be captured by the PSS and better support provided.

5. Outreach Comments and Student Training

In conducting the research discussed in this report, we have consulted with the City Engineer of the City of Newburgh, representatives of the New York State Department of Conservation, and staff of the Orange County Planning Department and Orange County Water Authority. We have also availed ourselves of materials accessible on the web sites of the municipalities discussed in this report.

Sara Davis, a professional master's degree student in the Department of City and Regional Planning at Cornell University, and Arash Beheshtian, a Ph.D. student in the Department, played instrumental roles in conducting this research. Sara Davis was the principal author of the second section of this report.

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7. Appendix: Plots of the time paths of model variables for the ACC-Par simulation

Figure 1: Projected Population Growth in the City of Newburgh (CN), Town of Newburgh (TN), and Town of New Windsor, (TNW) 2012-2035

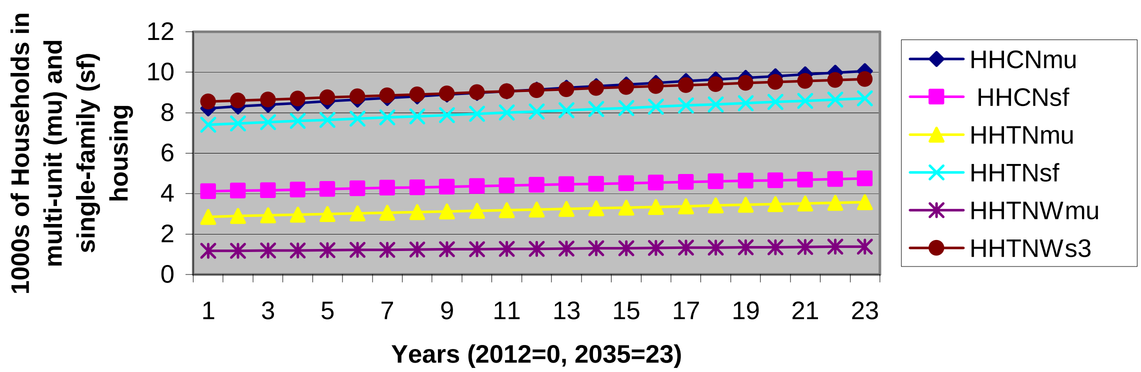
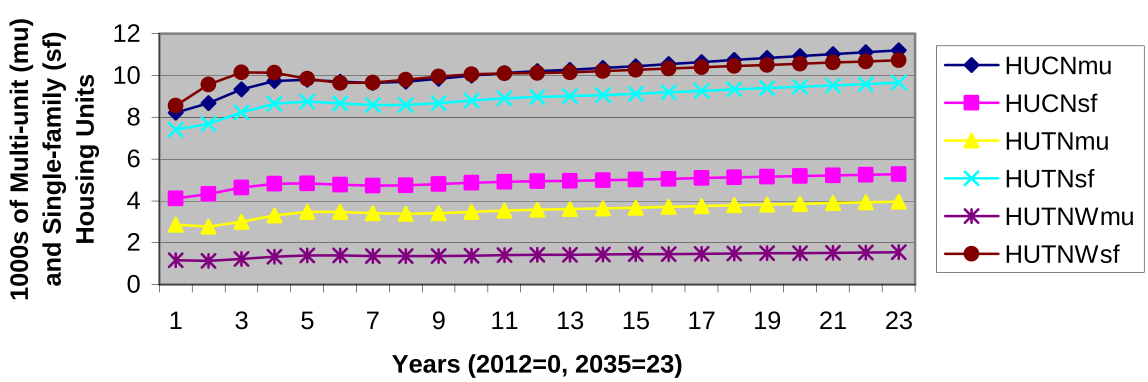


Figure 2: Projected Housing Development in the City of Newburgh (CN), Town of Newburgh (TN), and Town of New Windsor (TNW), 2012-2035



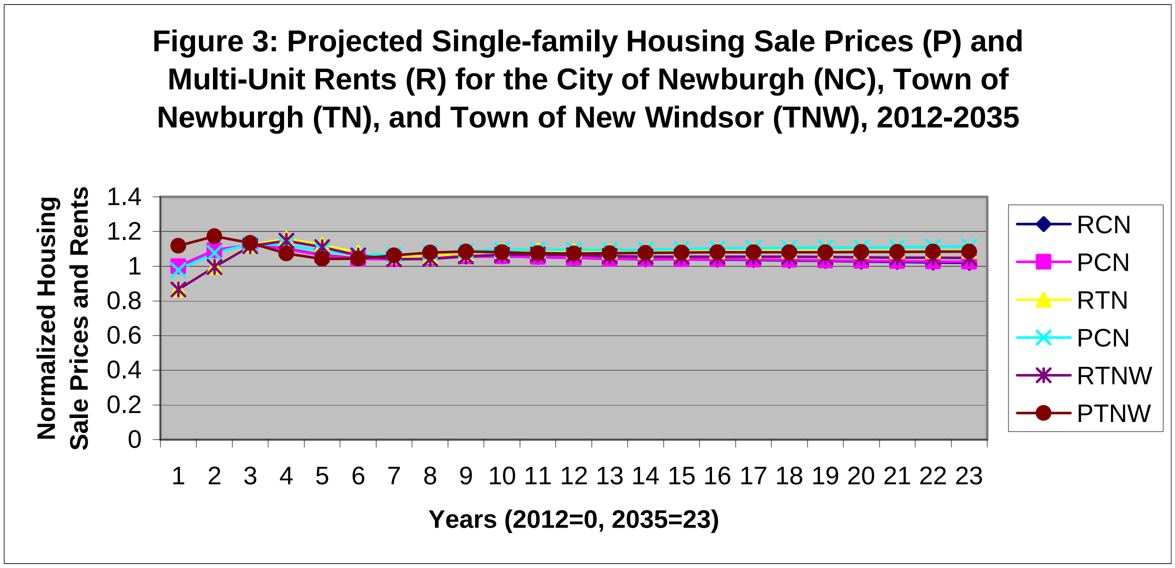


Figure 3: Projected Single-family Housing Sale Prices (P) and Multi-Unit Rents (R) for the City of Newburgh (NC), Town of Newburgh (TN), and Town of New Windsor (TNW), 2012-2035
Normalized Housing Sale Prices and Rents
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Years (2012=0, 2035=23)
RCN
PCN
RTN
PCN
RTNW
PTNW

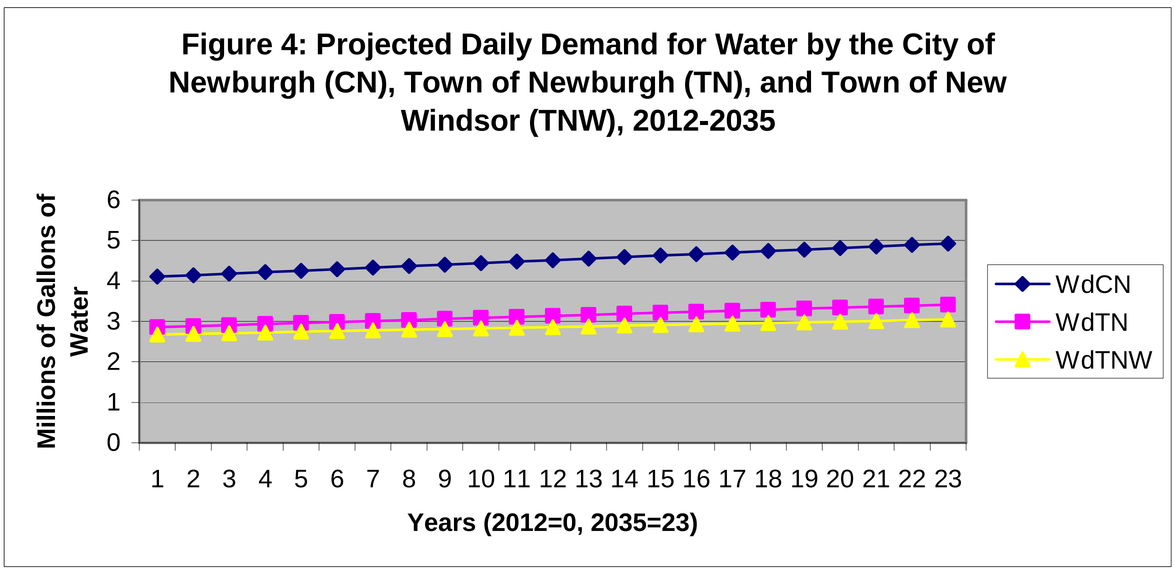
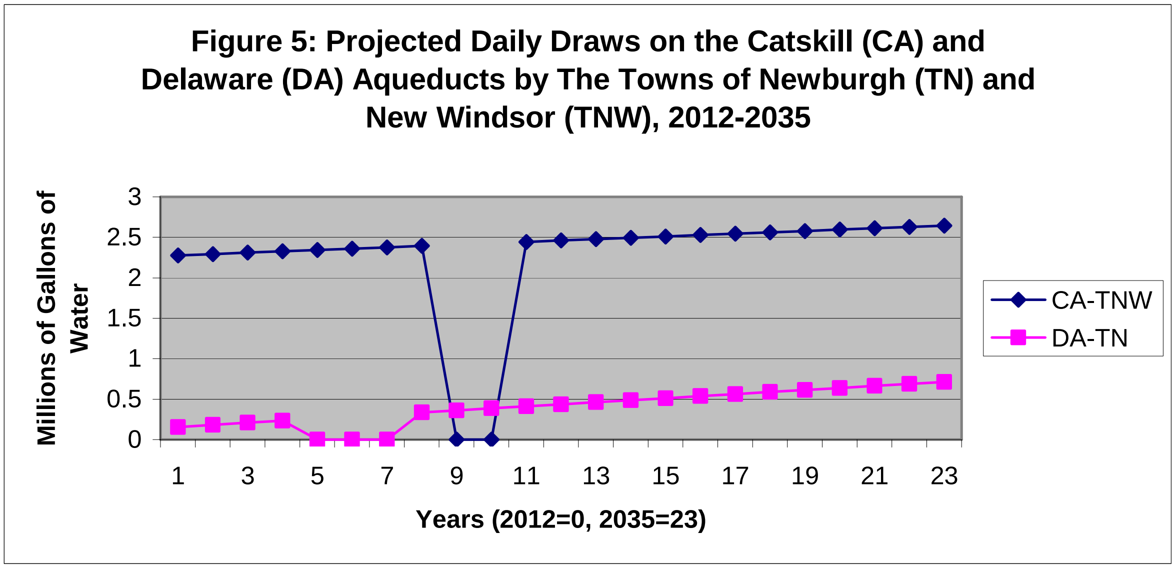
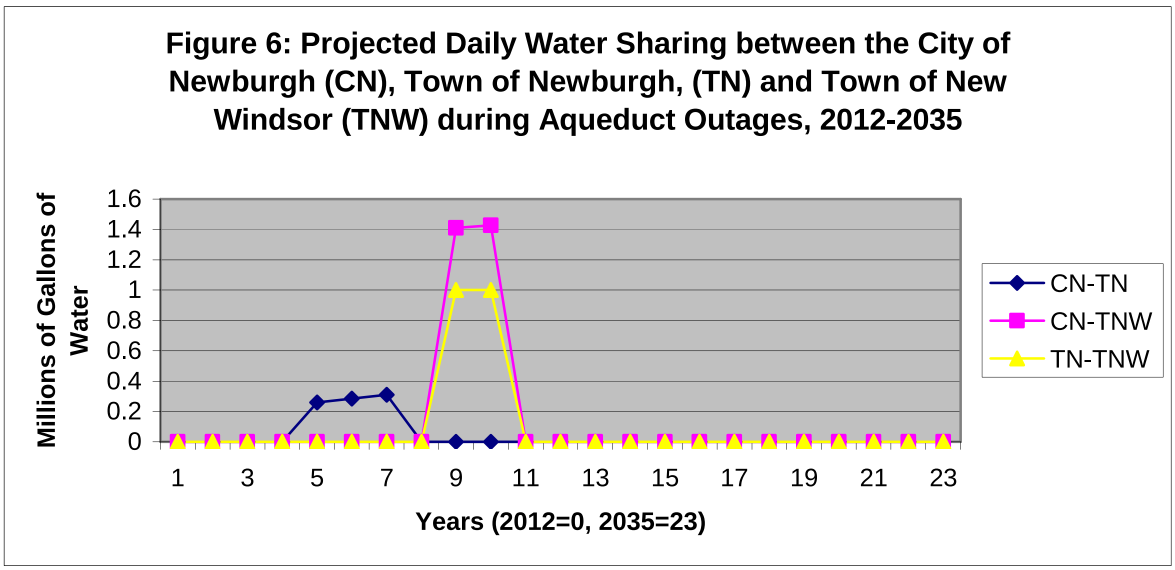


Figure 4: Projected Daily Demand for Water by the City of Newburgh (CN), Town of Newburgh (TN), and Town of New Windsor (TNW), 2012-2035
Millions of Gallons of Water
6
5
4
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Years (2012=0, 2035=23)
WdCN
WdTN
WdTNW





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