Estimating Potential Costs of Watershed Development on Drinking Water Treatment

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ABSTRACT

The capital and operating costs for drinking water treatment are generally a function of raw water quality as determined by the intensity of watershed development. This study uses a watershed build-out analysis coupled with a nutrient loading model and empirical water quality response models to compare the costs and benefits of water supply watershed land acquisition versus treatment process improvements for a reservoir system in south central Connecticut. Although the capital costs of land acquisition to maintain existing raw water quality in this particular reservoir system are similar to the alternative of upgrading treatment, long-term operating costs for the land acquisition approach are negligible in comparison. Whether land acquisition is implemented singly or in conjunction with treatment improvements, there are a number of potential future risks and unknowns concerning both water quality and water treatment that can be mitigated by water utility ownership and control of critical watershed areas.

INTRODUCTION

The South Central Connecticut Regional Water Authority (SCCRWA) is non-profit, public water utility that provide approximately 51 million gallons of water per day to an estimated 430,000 consumers in its region. In addition to its primary mission of providing its customers with high quality water at a reasonable cost, the SCCRWA is also charged with promoting the preservation of watershed land and aquifers. The SCCRWA owns more than 27,000 acres of land to protect water supply sources consisting of 10 active reservoirs, and 7 groundwater supply aquifers. Since the early 1980s, the SCCRWA has worked to purchase properties or conservation easements to protect 3500 acres of water supply watershed land at a cost of over $28 million.

The Safe Drinking Water Act (SDWA) amendments of 1996 brought increased emphasis to the role of source water protection in the multi barrier approach to drinking water quality management. The water quality of lakes and reservoirs is largely a function of watershed land cover, with increasing forest cover generally being associated with lower nutrient loading and primary productivity (Omernik, 1977; Field et al., 1996; Wickham et al., 2000). The replacement of forest land with urban and suburban land uses, including impervious surfaces and managed lawns, inevitably results in undesirable eutrophication of drinking water reservoirs, including increased algae blooms, hypolimnetic oxygen depletion, taste and odor compounds, disinfection byproduct precursors, and dissolved manganese (Bernhardt, 1980; Walker, 1983; Cooke & Kennedy, 2001).

Source water quality is the primary driving factor in determining the level of treatment process sophistication necessary to achieve drinking water standards and goals. More degraded raw water quality can lead to higher capital costs to achieve treatment objectives, particularly as driven by the need to design for episodic or worst case water quality events. Higher operating costs can result from the advanced treatment processes themselves and/or water quality related operational issues, such as decreased filter run times, higher chemical dosing requirements, increased residual disposal costs, and frequent process adjustments due to higher water quality variability. Given the relationships between watershed development and the loading of nutrients and other contaminants to water supply reservoirs, it can be expected that more protected watersheds will have better and more consistent raw water quality and thus lower treatment costs.

QUANTIFYING ECONOMIC BENEFITS OF WATERSHED LAND PRESERVATION

In some cases, the cost benefits of watershed forest land preservation are relatively straightforward to quantify. Water supplies serving small and large cities throughout the country such as Boston, New York City, Syracuse, and Portland, ME have been able to save tens of millions to billions of dollars in capital and operating costs by investing in watershed land preservation to avoid constructing filtration plants (ECONorthwest, 2004; Postel and Thompson, 2005). A survey of 27 US water suppliers concluded that treatment & chemical costs decreased about 20 percent for every 10 percent increase in watershed forest cover (Ernst, 2004). Power and chemical costs per million gallons to treat water from the SCCRWA reservoir systems with pristine forested watersheds are up to an order of magnitude lower than those with developed watersheds.

Watershed Land Acquisition Programs and Financial Benefits. Although it is generally presumed that preserving more undeveloped land in water supply watersheds will maintain better raw water quality and therefore lower treatment costs, financial benefits of acquiring additional land to protect drinking water sources will vary on a system specific basis. There is limited cost-benefit information to support system specific decision-making on how to allocate financial resources among the various components of the multi barrier approach. Factors to be considered, in addition to the characteristics and location of properties being considered for purchase, include the current extent of protected watershed lands, existing watershed land uses, current raw water quality, existing treatment processes, and the degree of protection afforded by municipal land use regulations. For example, in the case of a reservoir system with a near fully built-out watershed served by an advanced treatment process, it might be argued that acquisition of the few remaining private undeveloped watershed properties will have negligible protection value. This contention might also be made for a predominately forested watershed where the vast majority of the watershed is permanently protected open space. However, in either case there may be a host of risk reduction benefits associated with additional land protection that may be difficult to express in monetary terms. Factors that would favor additional land acquisition include critical large privately undeveloped parcels in sensitive areas, an existing treatment process that is not sufficiently designed for handling episodic water quality events such as algal blooms, and land use regulations or economic pressures that increase the likelihood of future incompatible watershed development.

Dollars for Watershed Land Acquisition versus Competing Priorities. In an era of declining water demand and water utility revenue (Beecher, 2010), dollars for watershed land acquisition are competing against elevated priorities associated with upgrading aging infrastructure serving water treatment and distribution systems (AWWA, 2012). Although significant and permanent impacts to water quality and the cost of treatment can cumulatively result from watershed development, these impacts often occur on a long-term incremental basis and thus economic considerations can sway decision-makers to cut or defer costs associated with land acquisition for more pressing short-term needs whose benefits may be more easily measured. The risk associated with this approach is that as economic conditions improve, increased development pressure may increase land values to the point where acquisition of key watershed parcels is cost prohibitive, or development occurs at an accelerated pace that exceeds typical timeframes necessary to complete open space land transactions.

In an effort to weigh the potential economic benefits of watershed land acquisition versus the cost of additional treatment to address water quality degradation from future watershed development, the SCCRWA undertook a desktop analysis of one of its four active surface water supply systems known as the West River System to 1) estimate the potential magnitude and timing of future watershed development; 2) model the raw water quality changes that might occur from full build-out of the watershed; and 3) assess the implications of these water quality changes on the existing treatment process. A watershed build-out analysis along with modeling of nutrient loading and reservoir water quality response was conducted by the University of Connecticut Center for Land Use Education and Research (CLEAR) (Dietz et al., 2009). This was followed by a collaborative effort among the SCCRWA, Water Resources Services (WRS), and CH2M HILL, to assess how the modeled water quality changes might affect the existing treatment process, what alternatives are available to avoid or address these changes, and the relative costs of each alternative.

Assumptions. The following simplifying assumptions were made to facilitate this analysis:

- Ratio of developed land to number of buildings stays constant. As explained below, this was necessary to link the build-out analysis to estimates of nutrient loading using land use export coefficients.
- Zoning regulations remain unchanged.
- Maximum development efficiency of 80%. In other words, it is assumed that 20% of total developable land as determined by zoning, wetlands, and other constraints, will remain undeveloped at full watershed build-out.
- For modeling purposes, including volume and surface area characteristics, the five reservoirs making up the West River system were treated as one water body.
- No internal total phosphorus loading to the reservoir system. Based on an extensive reservoir water quality database, internal phosphorus loading in the West River reservoir system does not appear to be significant relative to external loading.

- Variability associated with reservoir water bypasses (water withdrawals, spillway overflow and downstream releases) remains constant

WATERSHED BUILD-OUT ANALYSIS

The West River Reservoir System is comprised of five reservoirs in south central Connecticut (Figure 1) with a total watershed of about 3,580 hectares. About 90% of the total watershed area is currently undeveloped, with 55% owned and controlled by the SCCRWA. SCCRWA data indicates that the trophic status of this reservoir system is mesotrophic with respect to nutrients, transparency, and algal biomass. Although the raw water quality is generally excellent, the current direct filtration process and drinking water production is occasionally hampered by relatively moderate levels of filter clogging algae, especially in the higher demand summer months. The vast majority of the watershed is zoned for large lot residential development (approximately 1.5 to 3 acre lot size), with a few small isolated areas zoned for higher density residential and commercial/industrial uses. To conduct the watershed build-out analysis, CLEAR used CommunityViz® Scenario 360, an ArcGIS extension which allows users to analyze multiple geographic build-out scenarios in order to project development for an area based on existing land use patterns, open space, environmental restrictions, and zoning regulations. Development is expressed by CommunityViz® as the numbers and locations of buildings. Geospatial data layers and land use regulations were collected for each watershed municipality and were used to identify existing development and constraint areas where it was assumed no future development would occur (Table 1). Existing buildings were identified using digital aerial imagery and represented as point features in a newly created GIS layer. Hydrologic features and protected open space, including streams and wetland soils and their regulated buffers per local regulations (50 to 200 feet) functioned as constraint areas in the build-out analysis. The overall total area representing constraints to buildable land was 2471 hectares, representing about 69 percent of the total watershed.

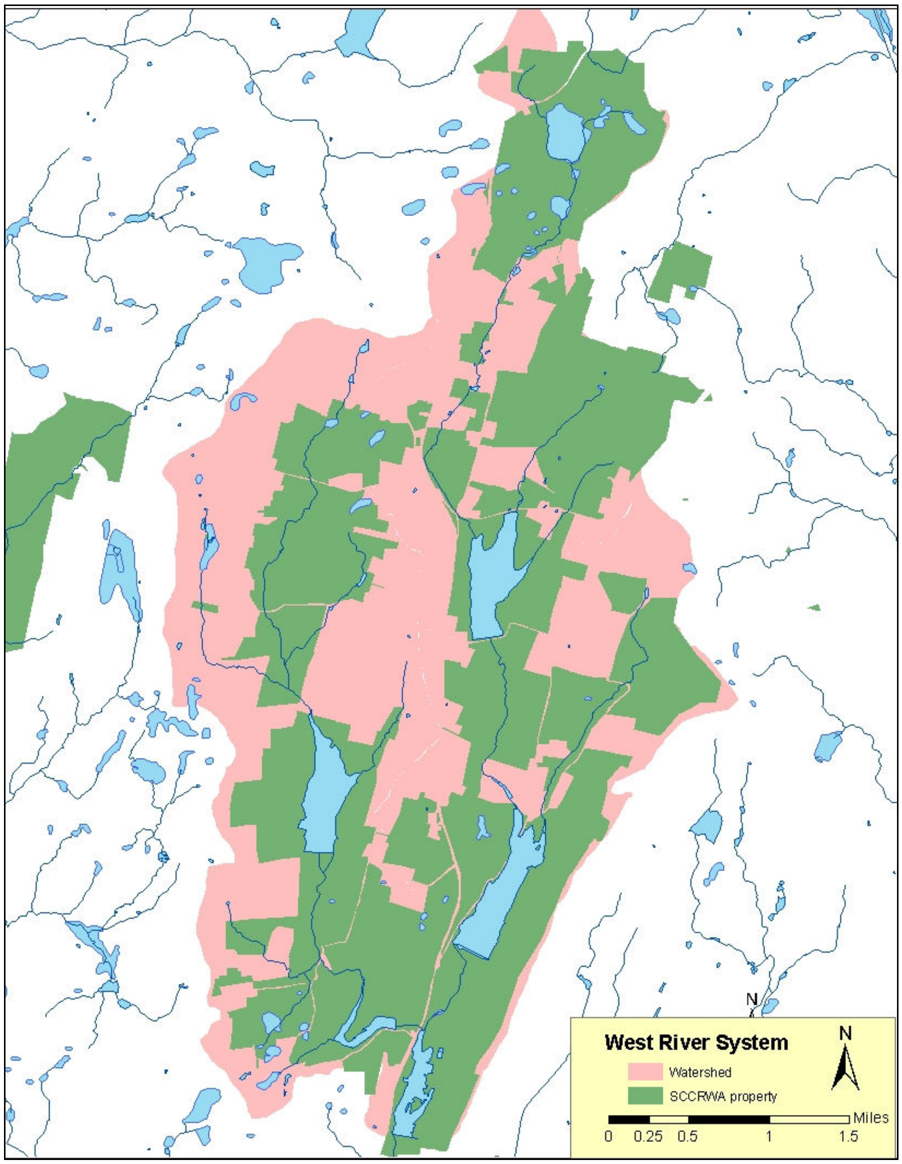

Figure 1-West River Watershed

Table 1. Geospatial data layers used for build-out.	
Data Layer	**Function**
Parcel boundaries	Land-use layer
Zoning designations	Land-use layer
Hydrology lines	Constraint layer
Hydrology polygons	Constraint layer
FEMA Flood zones	Constraint layer
Wetland Soils	Constraint layer
Developed Edge Parcels	Constraint layer
Regulated Wetland Upland Review Areas (Buffered hydrology lines, polygons, wetland soils)	Constraint layer
SCCRWA Property	Constraint layer
SCCRWA Conservation Easements	Constraint layer
CT Department of Environmental Protection Property	Constraint layer
Municipal Properties	Constraint layer
Existing building points	Existing buildings
West River Watersheds	Study area

Build-out analysis results. CommunityViz® can provide build-out scenarios under multiple development efficiency factors. Even though the software predicts the number of buildings that can be placed on undeveloped land as allowed by zoning and specified constraint layers, in practice the full number of buildings is rarely achieved. An efficiency factor of 80 percent was used to represent the worst case development scenario used to form the basis for subsequent analysis of water quality, treatment implications, and financial impacts. As an example, if 10 acres of land were available for development in a 1 acre zone, it is assumed the end result of full build-out would be only 8 buildings(or developed lots) rather than 10.

The map generated using CommunityViz®, including zoning designations, existing buildings, and estimated new building locations under an 80% efficiency build-out is shown in Figure 2. While these results are useful from a planning perspective, they were not in a format suitable for the next phase of the analysis, which was to use land use export coefficients to estimate pre and post build-out nutrient loading to the reservoir system. In order to compare existing versus post-build-out developed area, a ratio of building units to developed land was established Using CLEAR land cover data based on 30 meter satellite imagery data from 1985, 1990, 1995, and 2002 (Figure 3), a historical rate of development (5.4 acres/year) was established and used to estimate developed land at the chosen study starting baseline year of 2005. The 2005 ratio of developed area to building units was estimated to be 0.46 ha/building. Coupling this ratio with the assumed rate of development and the number of buildings at maximum build-out using CommunityViz®, it was estimated that full watershed build-out would occur in 2043. Areas as modeled of developed land under current and build-out conditions are shown in Table 2.

Table 2. Results of Watershed Build-out Analysis (Dietz et al., 2009)

Scenario	Total Buildings	Developed Land Area (ha)	Percent Watershed Developed
Existing	786	366	10
Full Build-out (Year 2043)	1227	571	16

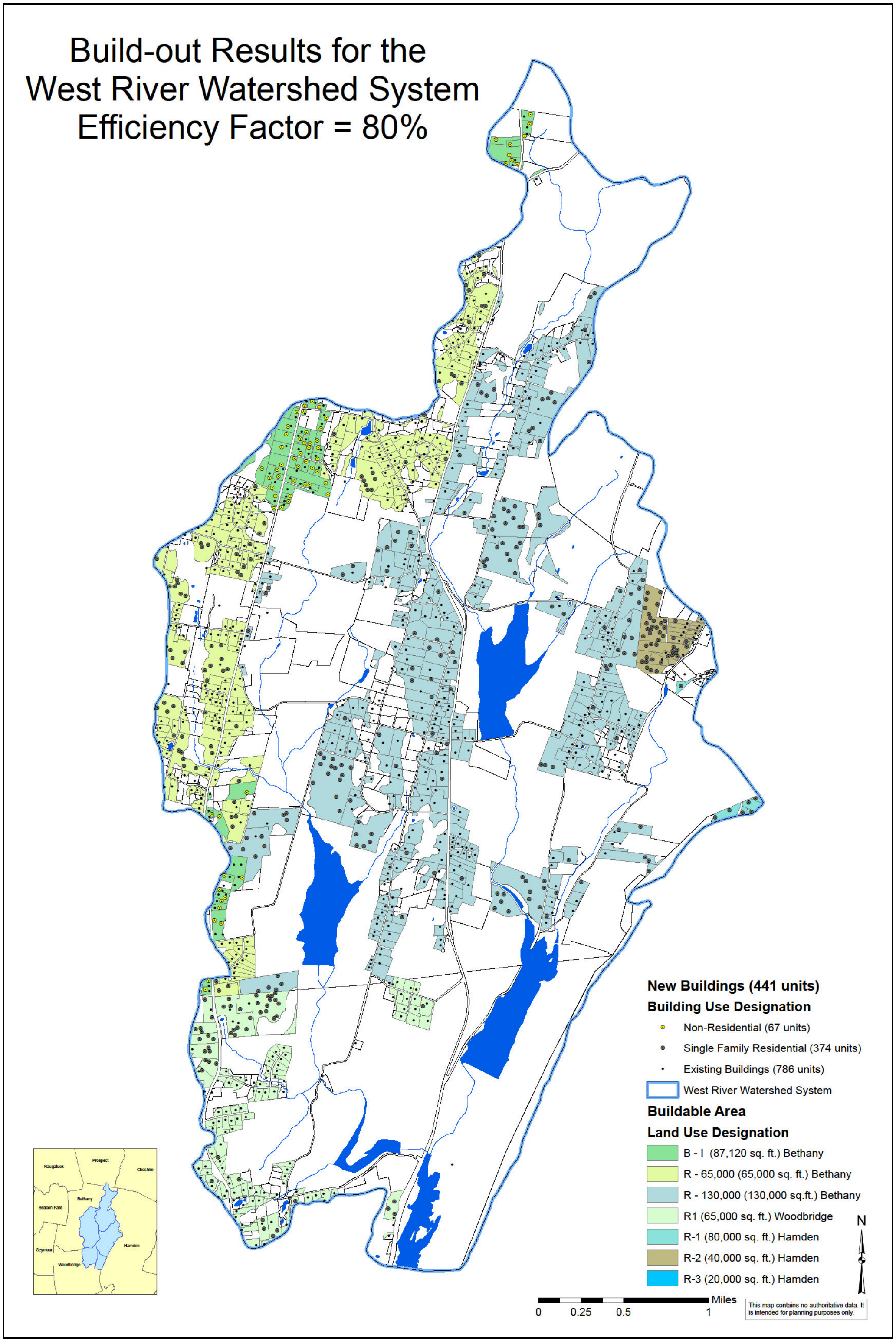

Figure 2 - Build-out Analysis Map of West River public water supply watershed. Areas shown in white are constraint layers and thus assumed not available for development (Dietz et al., 2009)

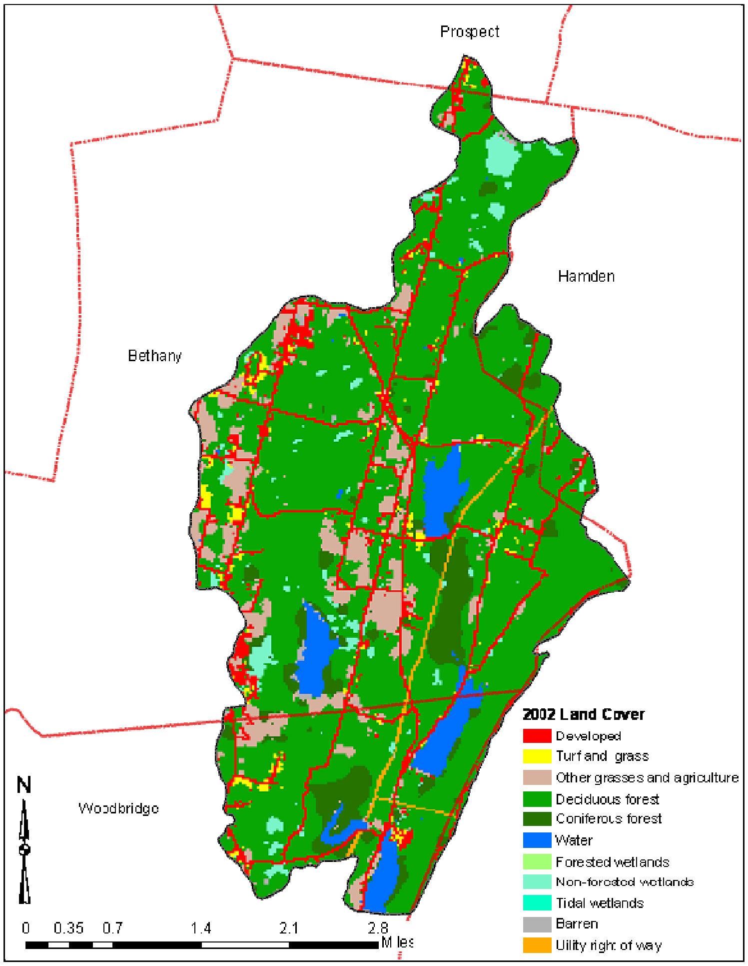

Figure 3 - CLEAR land cover data, West River Watershed (Dietz et al., 2009)

WATER QUALITY MODELING

Predicting the impacts of future watershed build-out on raw water quality involved: 1) utilizing nutrient export coefficients and a dynamic systems modeling software package to construct a mass balance model of algal nutrient inputs and outputs to the reservoir system under current and future build-out conditions; and 2) predicting water quality response from the resulting modeled nutrient concentrations under both scenarios using literature derived empirical relationships, and statistical relationships observed in reservoir water quality data collected by the SCCRWA.

Nutrient Loading Model. A dynamic systems modeling software (Stella®, High Performance Systems, Inc., version 8.0, 2003) was used to define the mass balance of total phosphorus (TP) and nitrogen (TN) in the West River reservoir system (Dietz et al., 2009). Watershed nutrient inputs under the existing and build-out scenarios were determined using estimates of atmospheric deposition (Yang et al., 1996) and adding the areas of developed and undeveloped land multiplied by corresponding TN and TP export coefficients developed for Connecticut lakes by Frink, 1991 (Table 3).

Table 3. Nutrient Input Values			
Parameter	**Value**	**Units**	**Source**
TN Atmospheric Deposition	10.1	kg $ha^{-1}yr^{-1}$	Yang et al., 1996
TP Atmospheric Deposition	0.043	kg $ha^{-1}yr^{-1}$	Yang et al., 1996
TN Export coefficient, Developed land	13.4	kg $ha^{-1}yr^{-1}$	Frink, 1991
TN Export Coefficient, Non-developed land	2.4	kg $ha^{-1}yr^{-1}$	Frink, 1991
TP Export coefficient, Developed land	1.55	kg $ha^{-1}yr^{-1}$	Frink, 1991
TP Export Coefficient, Non-developed land	0.07	kg $ha^{-1}yr^{-1}$	Frink, 1991

Although the West River system consists of five reservoirs, input parameters such as reservoir surface area and reservoir volume were combined and the system was modeled as one unit to simplify the analysis. Sinks of TN and TP in the model included mass removal of TN and TP (kg yr-1) from reservoir withdrawals and bypasses (spillage and releases) and settling. Individual annual average water bypass amounts (spillage and releases) at the terminal reservoir and treatment plant withdrawal volumes were determined over a 5 year period. These annual averages were then input into the model, which provided a degree of interannual variability in the model results. TN and TP settling velocities were adjusted until the system was in steady state. Internal loading of TP was not modeled in this analysis and based on monitoring data collected by the SCCRWA is not believed to be a significant TP contributor relative to external loading.

Water Quality Response Determinations. Predicting the impacts of watershed build-out to the drinking water treatment process posed a considerable challenge in that parameters typically generated by lake response models, such as chlorophyll *a*, are underutilized by water treatment professionals in determining drinking water treatment process needs. The following approaches were used to address this issue: 1) empirical model equations were selected from the literature whose results compared well to existing water quality in the West River system; 2) a literature search for information that quantitatively relates lake and reservoir trophic parameters(e.g., chlorophyll *a*, phosphorus) to raw water characteristics directly impacting drinking water quality and treatment such as cyanobacterial dominance, taste and odor compounds, and algal bloom probability, 2) review of literature for treatment requirements based on chlorophyll *a*; and 3) examination and use of statistical relationships observed in SCCRWA reservoir water quality data to correlate modeled parameters with widely used drinking water quality parameters. Table 4 lists the empirical models and statistical relationships used to predict water quality in response to modeled nutrient concentrations.

Chlorophyll *a* as an indicator of raw water quality problems. Multiple literature sources suggest that a chlorophyll concentration of 10 µg/L is a reasonable threshold for assuming nuisance algae and cyanobacteria problems related to filter clogging and taste and odor that may make advanced treatment technologies more desirable or necessary. Janssens et al. (1993) created a decision tree that suggested solids removal such as settling or dissolved air floatation was warranted for raw water sources with turbidities greater than 10 NTU and/or chlorophyll *a* concentrations greater than 10 µg/L. The State of Oklahoma Water Resources Board (2005) established an average chlorophyll *a* criterion of 10 µg/L for water bodies with a "Sensitive Water Supply" designation. A study of a eutrophic drinking water reservoir in Kansas found a strong predictive relationship between chlorophyll *a* and the taste and odor causing algal metabolite geosmin, and concluded that the intensity and frequency of taste and odor events in drinking water supplied by the reservoir would consistently be reduced if mean concentrations of chlorophyll *a* were maintained below 10 µg/L (Smith et al., 2002). In addition to elevated phytoplankton biomass, elevated chlorophyll *a* concentrations can also typically associated with undesirable shifts in phytoplankton community composition. In an analysis of data from 99 north temperate zone lakes, Downing et al. (2001) found cyanobacterial dominance as a percentage of phytoplankton biomass increased nonlinearly with increased concentrations of nutrients and total phytoplankton biomass. In this study, 10 µg/L chlorophyll *a* was observed as an approximate breakpoint of where the risk of cyanobacterial dominance increased to greater than 10 percent and up to 80 percent with increasing chlorophyll *a* concentrations. In interpreting the response model results, we therefore made the assumption that 10 µg/L chlorophyll *a* represented a problematic condition for water quality and water treatment.

Water Quality Modeling Results. Existing condition and post watershed build-out modeling results for TP and TN as generated by the Stella® mass balance model and the response parameters in Table 4 are shown in Table 5. Post-buildout modeling predicts undesirable post-watershed build-out changes in average water quality conditions pertaining to trophic parameters, including a 52 percent increase in total phosphorus, 80 percent increase in algal biomass as represented by chlorophyll *a*, and a 24 percent decrease in water transparency. Using the rate of development determined by the historical land cover data (5.4 acres per year) also allowed a graphic projection of changing water quality as watershed development progressed before reaching maximum build-out (Figure 4).

Table 4 - Water Quality Response Model Equations

PARAMETER	EQUATION	SOURCE
Mean *Chlorophyll a* (Chl a) (µg/L)	-7.18+(0.229TP)+(0.022TN)	Frink and Norvell, 1984
Mean Secchi Transparency (SD) (m)	log(SD) = -0.473log(Chl a)+0.803	Rast and Lee, 1978
Peak Chlorophyll *a* (µg/L) (Average of three equations models)	$1.28TP^{1.05}$ $2.6(\text{Chl a})^{1.06}$ 3.4(Chl a)+0.2	Modified Vollenweider, 1982 Vollenweider, 1982 Modified Jones, Rast, and Lee, 1979
Minimum Secchi Transparency (m)	log(SD) = -0.473log(Peak Chl a)+0.803	Rast and Lee, 1978
Expected Cyanobacterial Dominance (%)	42.6(logTP)-25.82	Based on data from Watson et al., 1997
Bloom Probability Chlorophyll a >10 µg/L (% of Summer)	Calculated based on equations developed by Walker, 1984 using a natural log mean chl a standard deviation of 0.5. See source.	Walker, 1984
Color (CU)	-26.774ln(SD)+53.622 ; R^2 = 0.66	Statistical relationship using SCCRWA water quality data. Mean and peak values calculated using modeled mean & peak Secchi transparency
Turbidity (NTU)	-0.8114ln(SD)+1.8572; R^2 = 0.54	Statistical relationship using SCCRWA water quality data. Mean and peak values calculated using modeled mean & peak Secchi transparency
UV absorbance (cm^{-1})	-0.1462ln(SD)+0.305; R^2 = 0.56	Statistical relationship using SCCRWA water quality data. Mean and peak values calculated using modeled mean & peak Secchi transparency

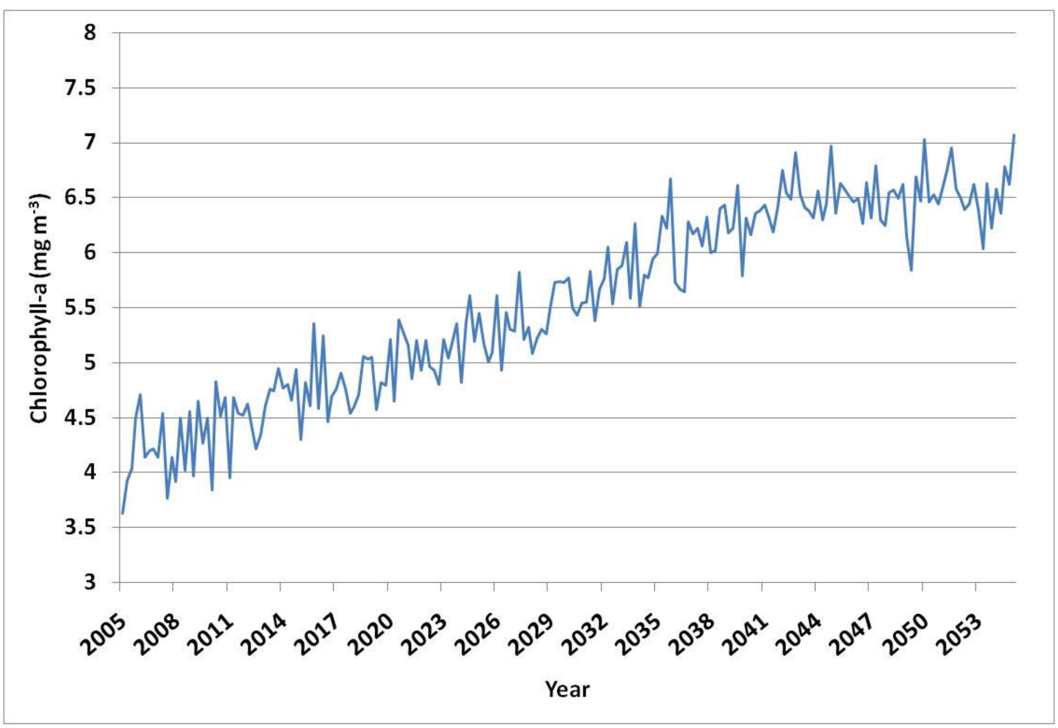

Figure 4 – Reservoir chlorophyll *a* steady state concentrations for build-out scenario.

The magnitude of these changes in average conditions in themselves, however, do not necessarily imply that drinking water treatment process will be affected enough to cause significant issues related to filtration, taste and odor, and cost. Similar to sizing of water systems for peak demand periods, it is the transient periods of degraded water quality, such as algal blooms and storm events, which dictate overall treatment design needs or limitations. These events often occur during the summer peak demand periods, when treatment process reliability is most critical. In Table 5, model outputs for peak chlorophyll and bloom probability, suggest that the West River Water Treatment Plant will be processing raw water under summer bloom conditions of substantially greater magnitude and duration under watershed build-out conditions, including nearly twice the amount of phytoplankton biomass and blooms that persist for weeks instead of days. In addition, increased phosphorus concentrations are projected to affect the composition of the reservoir algal population to favor increased dominance by cyanobacteria (bluegreen algae), which are notorious for producing the earthy-musty taste and odor compounds geosmin and 2-methylisoborneal (MIB) (AWWA, 2010). Also, of increasing concern is the propensity of many cyanobacteria to produce toxins, known as cyanotoxins, that target liver functions and the nervous system. Cyanotoxins have been placed on the United States Environmental Protection Agency's (EPA) Drinking Water Candidate Contaminant List for possible future regulation under the SDWA. Therefore, there is the potential for watershed development to not only increase the severity of existing production related treatment issues (filter runs during algal blooms), but to create new challenges that may affect the quality of water consumed by drinking water customers and/or require increased capital expenditures to address future regulated contaminants.

Table 5 – Modeled Water Quality at 80% Development Efficiency			
PARAMETER	**Existing**	**Post Build-out**	**Percent Change**
Mean TP (µg/L)	9	13.7	52
Mean TN (µg/L)	398	481	21
Mean Chlorophyll a (Chl a) (µg/L)	3.6	6.5	80
Mean Secchi Transparency (SD) (m)	3.4	2.6	-24
Peak Chlorophyll *a* (µg/L)	11.9	20.5	72
Minimum Secchi Transparency (m)	2.0	1.5	-23
Expected Cyanobacterial Dominance (%)	15	23	52
Bloom Probability Chlorophyll *a* >10 µg/L (% of Summer)	1.2	13.6	1133
Mean Color (CU)	20	28	36
Peak Color (CU)	28	42	52
Mean Turbidity (NTU)	0.85	1.08	26
Peak Turbidity (NTU)	1.31	1.52	16
Mean UV absorbance (cm-1)	0.12	0.16	33
Peak UV absorbance (cm-1)	0.21	0.24	18

WATER TREATMENT IMPLICATIONS

The response models predicted increases in average and peak chlorophyll *a* concentrations in the West River reservoir system, as well as algal bloom frequency and cyanobacterial dominance. Although the predicted post-development changes when expressed as an annual average may appear relatively moderate, the key drivers in determining treatment process adequacy for the West River system are seasonal episodic phytoplankton bloom events, which have a history of causing operational problems such as reduced filter run time and production capacity. At their present magnitude and frequency, these events are managed using in-lake management techniques, including aeration, source selection, and depth selective withdrawal. The model predicted post-development changes, however, are indicative of more intense and frequent bloom conditions above the 10 µg/L chlorophyll *a* threshold, with associated increased cyanobacterial dominance. These changes could pose a number of potential impacts to the treatment process and drinking water quality including:

- Decreased filter run time and associated decreases in plant production capacity;

- Increased water losses from filter backwashes;
- Increased chemical dosing;
- Decreased GAC filter media life;
- Increased taste and odor from algal and cyanobacterial metabolites;
- Increased disinfection by-products (DBPs) due to additional dissolved organic matter resulting from a more eutrophic reservoir system
- Challenges with meeting potential future regulations that include more stringent standards (e.g., turbidity, DBPs) or emerging contaminants (e.g., cyanobacterial toxins, pharmaceuticals and personal care products (PPCPs), etc).

The above potential impacts, especially those that limit production or impact customer's perceptions at the tap, would likely make current in-lake management measures less effective and would create justification for significant capital improvements to the treatment process. Adding further layers of treatment, while often providing significant benefits to treatment efficiency and finished water quality, can also add hundreds of thousands of dollars in annual operation and maintenance costs. Selection of advanced oxidation processes such as ozonation could also contribute to the formation of additional regulated disinfection by-products.

ALTERNATIVES AND COSTS

To assess the impacts and costs of the projected watershed build-out scenario, four alternatives for responding to the corresponding predicted water quality changes were considered and evaluated (Table 7):

1. No action.
2. Land acquisition;

3. Treatment improvements;
4. Land acquisition and treatment improvements;

No action. At full build-out, developed land in the West River water supply watershed is projected to increase from 10 to 16 percent. This level of development would still represent a relatively pristine watershed. However, the current treatment process experiences short-term filter run and production issues caused by what would be generally be considered moderate phytoplankton blooms from a limnological perspective. The modeled water quality responses from watershed development represent a near doubling of mean and peak phytoplankton biomass, increased dominance by nuisance causing cyanobacteria, and an order of magnitude increase in the duration of phytoplankton blooms. These changes could result in significant seasonal reliability issues in meeting peak summer demands. In addition, degraded water quality would be expected to increase annual operating and maintenance costs due to decreased filter efficiency (as quantified by increased water loss for filter backwashes), increased chemical dosing, and shorter GAC filter life. These additional costs are estimated to total about $40,000 dollars annually, as shown in Table 6. Although these costs may appear relatively modest, the primary impacts of the build-out caused water quality degradation would be seasonal limits on water production due to decreased filter capacity. This would pose unacceptable seasonal water system reliability issues for the SCCRWA and thus “no action” is not considered a viable or sustainable long-term alternative. Aside from some modest improvements that might be realized by installing post-development stormwater system retrofits, the water quality changes caused by development would be largely irreversible. An evaluation of watershed retrofit costs associated with urban stormwater systems in North Carolina projected costs on the order of $20 million to $30 million per square mile of watershed were typical for retrofits removing only about 20 to 30 percent of the TP load (Hunt et al., 2011). Furthermore, retrofit opportunities for residentially development are likely to be limited and post-implementation nutrient loads could still be an order of magnitude higher than forested land.

Table 6 – Estimated Costs of Watershed Build-out No-Action Alternative		
Description	**Annual Cost**	**Explanation**
Coagulant Additions	$2200	Assumed additional 20,000 lbs/yr at $0.11/lb based on turbidity increase
Increased Filter Backwashes	$11,000	Assumed 164,000 gpd increase (20%) in finished water used for backwashes (water production cost = $180/million gallons +/-)
GAC Filter Media Replacement	$27,000	Assumed increase in replacement frequency from every 5 to every 3 years

Land acquisition. In the West River watershed, the SCCRWA has identified properties of undeveloped land worthy of preservation totaling about 480 acres. This would account for almost all of the 205 hectares (506 acres) of land projected to be developed in the CommunityViz® build-out analysis and thus avoid the model projected water quality impacts due to development land use changes. Unlike other alternatives presented here, land acquisition would also provide some level of risk reduction from future risks and unknowns that could affect water quality or treatment requirements, such as changes to local land use regulations, new regulated drinking water contaminants, stream flow regulations and the effects of climate change. There are also numerous additional social, environmental, and economic benefits of maintaining open space forest lands in the SCCRWA's region. Assuming a per acre cost of 25,000 dollars for raw undeveloped land in the SCCRWA region results in a total purchase cost of $12 million. Annual costs for owning the land, including Payment in Lieu of Taxes (PILOT), maintenance, and security patrols are estimated to be about $6,000. These expenses could be at least partially offset by income from commercial logging and firewood sales.

Treatment improvements. The modeled post build-out water quality changes include more frequent and intense phytoplankton blooms and increased dominance of cyanobacteria, with small increases in color and turbidity. Avoiding the resulting losses in filter and plant capacity, would require additional treatment to enhance solids removal prior to filtration. Dissolved air flotation (DAF) is often used to address the raw water quality conditions typical of the West River system, including low to moderate turbidity and elevated algal cell counts. In addition to mitigating the watershed build-out impacts, DAF would also improve existing filter runs and better tolerate the seasonal algal blooms that occur under current watershed development conditions. Since DAF could not be relied upon to remove additional dissolved organic matter, including taste and odor compounds from cyanobacteria, it is assumed that the GAC filter life would decrease under this scenario from 5 years to 3 years resulting in an annual cost increase of $27,000. It is estimated that the finished water used for backwashes would be reduced by about 100 MG/year resulting in a savings of $18,000 annually. However, capital costs for a DAF system would be substantial, estimated at $11 million, and annual operation and maintenance costs are forecast to be about $315,000, resulting in a net cost of $324,000.

Land acquisition and treatment improvements. Acquiring 480 acres of water supply watershed land and upgrading the treatment process as discussed above would have multiple long-term benefits to the SCCRWA and its customers, including improved plant capacity, preservation of existing product quality, and reduced risk from unknowns related to water quality or future drinking water regulations. By maintaining pristine raw water quality and minimizing problematic phytoplankton blooms, it would be expected that the DAF system would operate more efficiently and that GAC filter life would be maintained near present conditions, resulting in slightly lower annual operating costs. Ensuring the preservation of watershed land would also be a reduction in future risks and unknowns that could affect water quality or treatment requirements. All of these benefits need to be weighed against the substantial costs, including an estimated $23 million in capital costs and annual operating costs approaching $300,000, all borne by SCCRWA ratepayers.

Table 7. Summary of Alternatives

Alternative	Capital Cost	Annual O&M Cost Increase	Comments
No Action	$0	$40,200	Increased water loss, increased GAC filter media replacement, additional coagulant, Long-term reliability issues
Land Acquisition	$12M	$6,000	Taxes, lands maintenance
Treatment Improvements	$11M	$324,000	Enhanced solids removal, backwash water savings, increased GAC filter media replacement
Land Acquisition & Treatment Improvements	$23M	$291,000	Enhanced solids removal, backwash water savings, taxes, lands maintenance

DISCUSSION

The watershed analysis and response modeling predicted that future water quality will degrade with increased developed land in the watershed. More importantly, it provides insights into how acquiring critical water supply watershed properties might avoid water treatment costs in the future. Although the capital cost of purchasing currently undeveloped privately owned lands in the West River watershed are comparable to what would be the likely next step in treatment process upgrades, the ongoing cost of land preservation costs is negligible in comparison to the estimated $300,000 annual operating and maintenance expenses associated with a new DAF system. Although there would be operational benefits to be realized from upgrading the treatment process even under present water quality conditions, these costs need to be carefully considered in the context of permanent long-term changes in customer water use trends. Similar to trends observed nationally, customer demand in the SCCRWA's service area is in a long-term decline due to factors such as more efficient plumbing fixtures and appliances, decreasing water use by industrial customers, and changing demographics. Resulting declines in water revenues increase competition for capital dollars for water infrastructure improvements and the SCCRWA is and will continue to be seeking opportunities to reduce operating expenses to minimize future financial impacts upon its customers.

Although in this case land acquisition comes at a considerable price, ongoing operation and maintenance costs are de minimis in comparison to engineered treatment solutions. Regardless of whether land acquisition is implemented singly or in conjunction with treatment improvements, there are a number of potential future risks and unknowns concerning both water quality and water treatment needs that are difficult to quantify but can be partly or wholly mitigated by water utility ownership and control of critical watershed areas. These include:

- Changes to local land use regulations or judicial reversals of land use decisions that result in less protection of drinking water sources;
- More stringent drinking water standards, including lower Maximum Contaminant Limits for existing regulated contaminants and/or regulation of new emerging contaminants such as cyanobacterial toxins and PPCPs;
- More human activities, even those associated with well-designed development projects, that inherently pose more risk of water quality incidents, such as transportation spills or septic failures;
- New rules for instream flow to protect aquatic life below water supply dams, recently passed in Connecticut, and being considered in other states, will cause some reservoirs to experience lower seasonal water levels that could alter thermal structure and nutrient dynamics, potentially increasing phytoplankton biomass at water intake depths.

Maintaining watershed conditions that minimize nutrient loading and maintain natural hydrology will help to counteract these effects;

- Climate change, which has the potential to negatively impact water quality, water quantity, and water supply infrastructure such as dams, including extreme storm events and drought. Maintaining forested watershed conditions will help to alleviate the severity of these impacts, both by moderating the hydrology and water quality impacts of these events.

Despite the financial challenges posed by the ongoing trend of reduced water demand and revenue, the SCCRWA continues to recognize the value of preserving critical lands needed for long-term source water protection. In 2007, the SCCRWA established a goal of protecting an additional 3000 acres of watershed land using fee simple acquisition and/or purchase of conservation easements. The costs of these future land transactions are proposed to be partially offset by the ongoing sale of SCCRWA land that does not drain to drinking water sources and is not needed for the water supply system. Although the economic downturn evident since 2008 has presented challenges in maintaining the SCCRWA's land acquisition program, it has also created opportunities in the form of lower land prices and sellers willing to negotiate more favorable terms for completing real estate transactions, including phased purchases over multiple years. This has allowed the SCCRWA to continue to purchase significant system watershed parcels despite a notably reduced annual budget. In addition, the SCCRWA has developed a matrix to quantitatively rank and prioritize watershed parcels based on multiple factors concerning source water protection value, treatment capabilities, and overall importance in the context of the entire water system.

This type of analysis to compare the value of watershed land ownership versus additional treatment is site specific. Depending on factors such as existing watershed land use or the type of treatment already in place, analysis of other water systems could yield different results. An important future research need for applying lake models similar to the one used here includes investigating existing relationships between reservoir trophic parameter concentrations (typically modeled total phosphorus, chlorophyll, and Secchi transparency) with the level of treatment needed for water supplies (e.g., direct vs. conventional treatment, advanced oxidation, etc.), as well as the resulting capital and operating costs of treatment.

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