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A SIMPLE MODEL TO ENCOURAGE DECISIONS BASED ON ALTERNATIVE FUTURES

And a Sample Application to Total Impervious Area in the Snohomish River Basin

by

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Abstract

Local government planning decisions are often based on projections of population and other variables 20 years into the future, but changes in some natural systems occur over much longer time scales. This makes it difficult for decision-makers to adequately consider the long-term ecological consequences of their actions. As a result, social values for protection of natural resources may be systematically under weighted.

This paper describes a simple S-curve model that can be used to gain insight into long-term trends further into the future. While this approach does not consider spatial patterns of development and other important variables, the results can encourage discussion and more detailed analysis of alternative future scenarios.

The model is developed and demonstrated using preliminary estimates of total impervious area in the Snohomish River basin. The historical data on human population and housing units in Snohomish County fit very well with an exponential curve. The historical change in total impervious area is assumed to be exponential as well, and estimates for some recent years are available from analysis of satellite imagery.

Because many resources such as land and water are finite, exponential consumption of these resources will eventually reach a limit. If total impervious area were to continue increasing exponentially, it would take only 33 years to reach a practical limit where all land outside of forests and farms in the Snohomish River basin would be fully developed. There would be no place left for new development.

Slowing the proliferation of impervious area through low impact development and more intense redevelopment of existing impervious areas will provide opportunities for growth over a longer period. To be sustainable, the rate of expansion must decrease in the future. A smooth transition from exponential expansion to a steadily decreasing rate of change can be modeled as an S-curve.

The model can be used to develop and evaluate alternative future scenarios at a coarse scale. The desired long-term limit and the year in which the rate of expansion begins easing can be changed, allowing comparison of alternative future growth paths. A similar approach can be used for many other indicators, such as the filling of wetlands, hardening of shorelines, or appropriation of water. While the model does not predict exactly where and when change will occur, it provides a simple graphical view of the amount of change that is needed or allowed to achieve a preferred future alternative. That information can be used to set near term targets that support the long-term goals. It also supports adaptive management by providing a reference for comparison with actual monitoring results to determine whether additional actions are needed to stimulate or limit change.

Introduction

Local government planners often use population growth and other estimates projected over a 20-year period to guide decisions. This time frame is not long enough to adequately consider the cumulative effects of changes to natural systems over longer periods. The effect of land use change on salmon habitat is one example. If any 20-year period were viewed in isolation, it would be difficult to predict that changes in land use would contribute to the listing of Puget Sound chinook salmon as threatened under the Endangered Species Act. Looking back over a 150-year period, however, it is clear that habitat degradation associated with land use change is one of the primary causes of the decline of salmon. The challenge for planners is how to look ahead over a similar 150-year period and describe alternative future scenarios so that decision makers can determine what actions are appropriate to move toward the preferred future.

This paper develops a simple model for projecting conditions far into the future using very basic assumptions. Traditional planning uses information that is more specific, and there are models available that are more detailed. Recent research shows that the ecological impacts of development can depend as much on location as on quantity, and spatially explicit models have been developed to evaluate different patterns of growth. These more detailed models and approaches can get very complex, and they are not necessarily more accurate beyond the 20 to 30 year time frame. Furthermore, it can be difficult for local governments and the public to understand and apply complex models.

The simple approach proposed in this paper is a more accessible first step to encourage consideration of alternative futures in decision-making. Spatially explicit models can be developed to provide more detail and accuracy where needed to support decisions.

To illustrate the model with an example, it is developed using preliminary data about total impervious area (TIA) in the Snohomish River basin. Impervious areas, such as pavement and rooftops, change the way water moves across the landscape by preventing it from soaking directly into the ground. TIA was chosen as an example because it is directly influenced by local government decisions and it is strongly correlated with environmental variables such as peak flows and erosion, water quality, and biological integrity of streams (Klein 1979; Booth *et al.* 2002). The net effect from impervious surfaces can be reduced through stormwater facilities and other methods, but TIA is used here instead of effective impervious area because TIA can be estimated from readily available satellite images. The data used in the example is extremely limited and is intended only to demonstrate how the model can be used.

The section called Application to Alternative Futures Analysis demonstrates how the model can be used to evaluate alternative future scenarios expressed through different long-term goals and action timeframes. Similar analysis could be done for other variables of interest as described in the Areas for Future Research and Development section, which also proposes additional validation for the model.

Snohomish County Historical Data and Exponential Growth

Analysis of Snohomish County human population and housing unit data shows exponential growth. The white circles in Figure 1 show the Snohomish County population from 1900 to 2000

(Forstall 1995; Census 2000). The exponential curve shown in black has an annual growth rate of 3.0%. The correlation between the actual data and the exponential model is very close. Statistically speaking, r-squared is 0.996, where 1.000 would be a perfect fit.

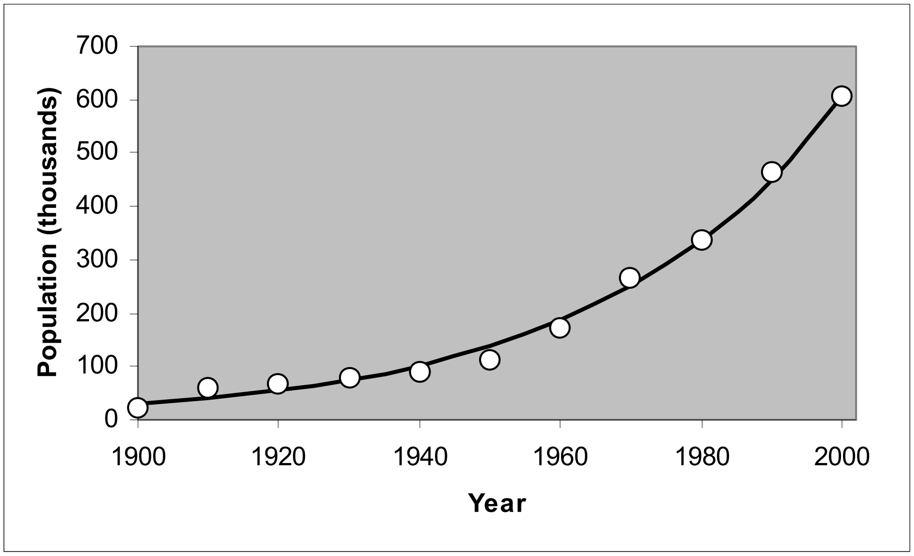

Figure 1. Human population of Snohomish County compared to exponential model with 3% annual growth (sources: Census 2000 and Forstall 1995).

White circles in Figure 2 show the number of housing units in Snohomish County over the 60 years for which data is available (Census 2000). The black curve shows exponential growth at an annual rate of 3.5%. The correlation is very close again, with an r-squared value of 0.992.

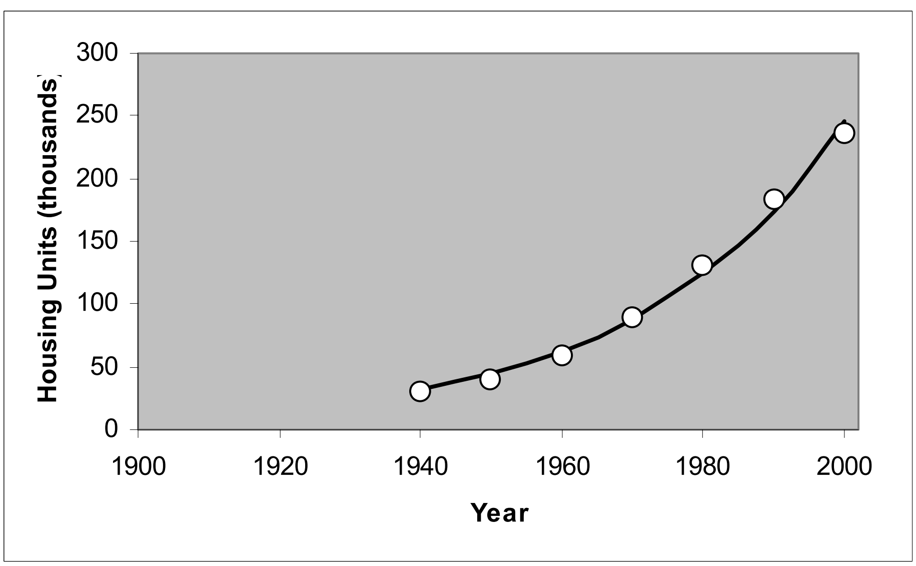

Figure 2. Housing units in Snohomish County compared to exponential model with 3.5% annual growth (source: Census 2002).

The growth rate for housing units is higher than for population because the number of people per housing unit declined from 2.9 in 1940 to 2.3 in 2000. With fewer people living in each house, more houses are needed to accommodate the population growth.

While the exponential curves fit the data well, Figure 2 shows that housing units in 2000 are slightly lower than the model would suggest. This could be temporary, like the dip in population in 1950, or it could be the beginning of a long-term change in the growth trend.

Total Impervious Area in the Snohomish River Basin

For the Snohomish River basin, analysis shows that TIA in 2001 was approximately 7.48% (Purser *et al*. 2003). Similar analysis was done on 1998 data, resulting in an estimate of 6.87% (Purser and Simmonds 2001). Slightly different methods were used in the two studies, and the results are only estimates. To make the results comparable, TIA for both years was estimated using the method recommended in the Purser and Simmonds 2001 report, which includes natural impervious areas such as open water and rocks as well as developed areas.

The annualized exponential growth rate between these two years is 2.9%. This is similar to the recent growth rates in population and housing units. More data, especially for earlier years, would help refine this estimate. Projecting this growth rate backward into history gives the black line in Figure 3. The white circles show the published estimates.

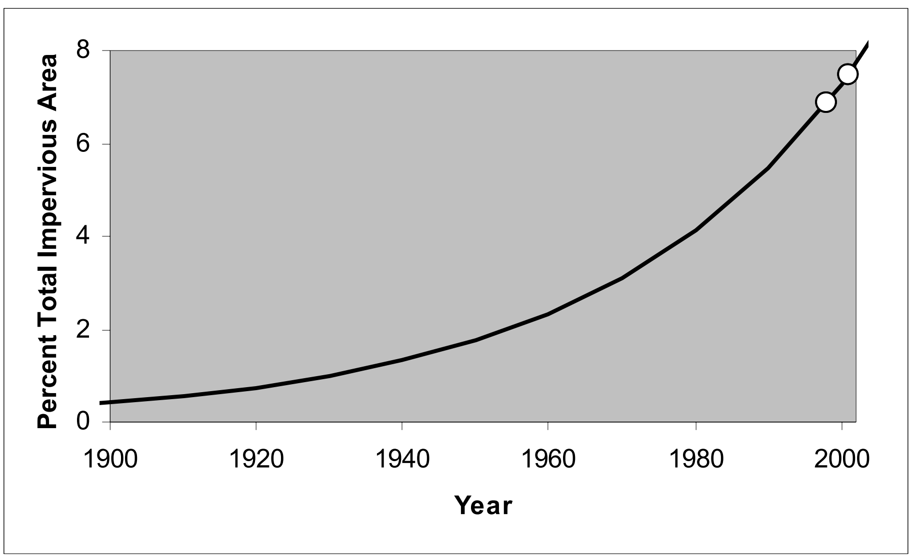

Figure 3. Exponential model of historical increase in total impervious area in the Snohomish River basin (sources: Purser and Simmonds 2001, Purser *et al*. 2003).

The same growth rate is projected 100 years into the future in Figure 4. If TIA continued to grow exponentially at the rate suggested by the 1998 and 2001 data, it would reach 20% in 2036 and 100% before the end of this century. This simple graph illustrates an obvious but important result: since it is impossible for TIA to exceed 100%, the current rate of growth cannot be sustained over the long term. At some point, there would be no place left for new development. This conclusion does not depend on the growth rate. Any constant rate of exponential (or even linear) increase, no matter how slow, would eventually reach any limit. It is only a matter of time. This result is not unique to TIA; it is equally true in every other case where something is increasing or decreasing toward a fixed limit.

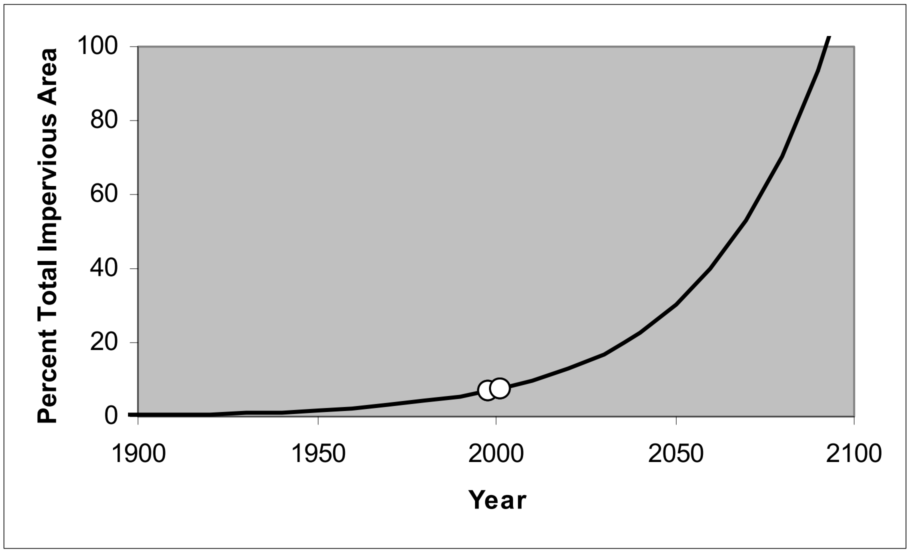

Figure 4. Future projection of exponential increase in total impervious area in the Snohomish River basin.

This example is based on only two estimated data points, so the numbers and dates are very preliminary. Changing the growth rate would change these dates. Lowering the growth rate to 2.5% would extend the time until TIA reaches 20% by 5 years. Raising it to 3.5% would shorten the time by about the same amount. No matter what the rate, though, exponential growth cannot continue indefinitely, so a different model will be needed to realistically project changes in TIA or other variables over a longer period.

S-Curve Model

Changes in many natural and human systems are subject to long-term limits. The number of fish in a small pond is limited by the carrying capacity of the pond. The consumption of oil in the world is limited by the available reserves. In both of these cases, change slows down as it approaches the limit.

The historic change in total impervious area looks like exponential growth, but the future change will be limited. To illustrate the model, a choice needs to be made about a reasonable limit. It is not realistic to use 100% as the upper limit because large areas of the basin have permanent restrictions on development. Forestlands cover 74% of the basin and agriculture covers another 5% (SBSRTC 1999). The choice of alternative limits is discussed in the section on Application to Alternative Futures Analysis.

In the meantime, picking 5% as a limit for TIA on forestlands, 10% as a limit in agricultural areas, and 75% as long-term average for all remaining areas would lead to an estimated practical limit for TIA in the Snohomish River basin of 20%. These numbers are similar to those found in studies relating land use to land cover (Prisloe 2001). This limit is chosen to illustrate the model, and should not be interpreted as a goal or desired level. A growing body of scientific literature suggests that water quality and salmon populations may suffer irreparable harm at TIA levels well below 20%. Booth and Reinelt (1993) and May *et al*. (1997) concluded that at 10% TIA, there was a demonstrable loss of aquatic system function.

Using the TIA estimates from 1998 and 2001 and the calculated growth rate, and assuming the transition from exponential to constrained growth occurs in 2001, the S-curve model total impervious area TIA(t) in the Snohomish River basin in year t is given by Equation 1. Figure 5 compares the graph of the S-curve with the exponential model.

$$\mathrm{TIA}(t) = \begin{cases} 7.48 \times 1.028^{(t-2001)} & \text{for } t \le 2001 \\ 20 - 12.52 \times 0.983^{(t-2001)} & \text{for } t > 2001 \end{cases} \qquad \textbf{Equation 1}$$

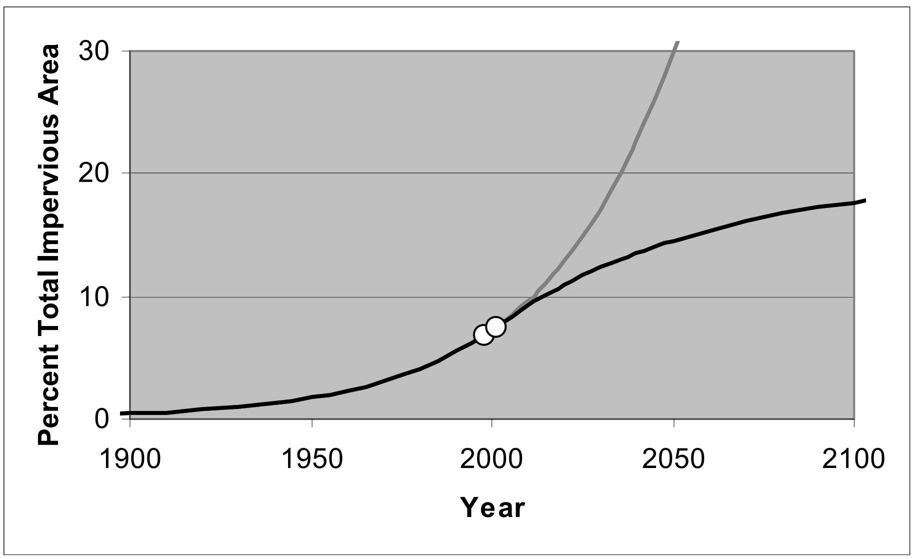

Figure 5. S-curve model of percent total impervious area in the Snohomish River basin (black line) compared to exponential model (gray line).

This graph shows that opportunities to develop additional lands can continue into the distant future without overshooting a chosen limit on TIA. To avoid the abrupt change that would occur if TIA hit the limit, the rate of expansion in TIA must slow down and keep slowing down in the future. Population growth and economic development can still be accommodated as long as they require a decreasing amount of new impervious area.

Low impact development can help reduce the rate of increase in impervious area. Concentrating an increasing share of future growth into areas that are already developed will also help. For the rate of increase in TIA to continue easing in the future, population densities will have to keep increasing. More people will need to be housed and employed in a given area without increasing TIA by building “up” instead of “out.”

If these and other approaches are not successful in reducing the rate of increase in TIA, the conversion of additional lands to impervious areas will continue to be exponential as seen above. The result will be a very abrupt change when all available lands are consumed, perhaps as early as 2036. There will be no new buildable lands after that point, so all growth will need to be accommodated within existing developed areas.

Application to Alternative Futures Analysis

The model above shows one theoretical future scenario for total impervious area in a watershed with a long-term limit on TIA. However, it is not the only possible scenario. If existing farms and forestlands were sold to private developers, for example, the long-term result could be more impervious area. Alternatively, a lower long-term limit might be appropriate if regulations restrict the amount of new impervious area, or if other areas are permanently protected.

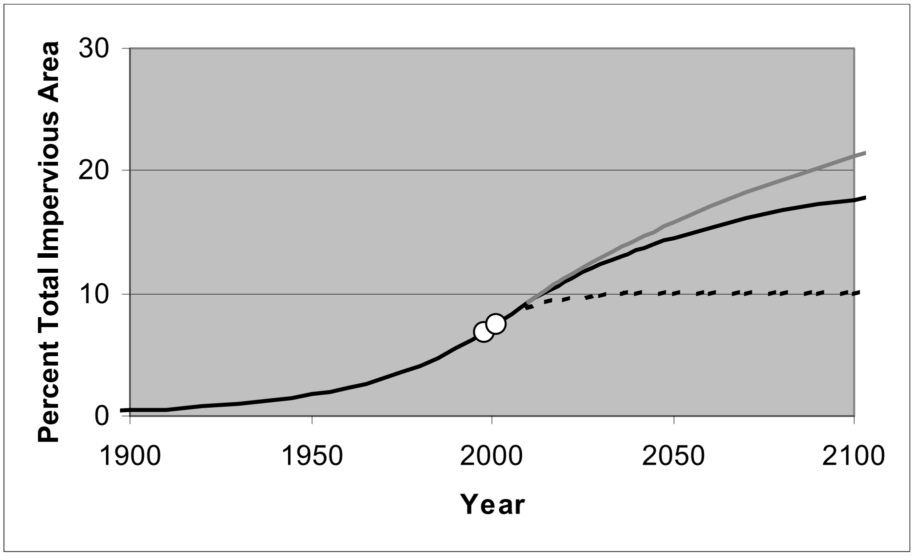

Figure 6. S-curve models of percent total impervious area in the Snohomish River basin with upper limits of 10 (dashed line), 20 (black line) and 30 (gray line).

Figure 6 uses the S-curve model to show three alternative future scenarios with different long-term limits on TIA. The dashed line shows how the growth rate must decrease more quickly if the target level is lower because there is less room left for future growth.

The S-curve model can be used to determine the amount of change that can be allowed in a given period to stay on track with the chosen long-term limit. Actual growth can be monitored and compared to the preferred scenario in the model. If actual growth is off track, additional actions could be taken to return to the preferred course.

In addition to changing the long-term target for TIA, alternative future scenarios could be constructed by changing the year in which the growth rate begins shrinking to stay within the limit. So far, the model has assumed that all future growth after 2001 is influenced by the practical limit on TIA. What if exponential growth continues until 2015 on the current trajectory? What if it continues until 2030? These are plotted on Figure 7 as a gray line and a dashed line, respectively.

Figure 7 reveals another important result. Limiting the growth rate sooner provides a smoother transition and allows growth to continue for a longer period before it flattens out. Conversely, delaying the transition leads to a more abrupt change down the road and more severe curtailments on development. In short, there will be more opportunity to develop new areas in the future if more areas are left undeveloped in the present.

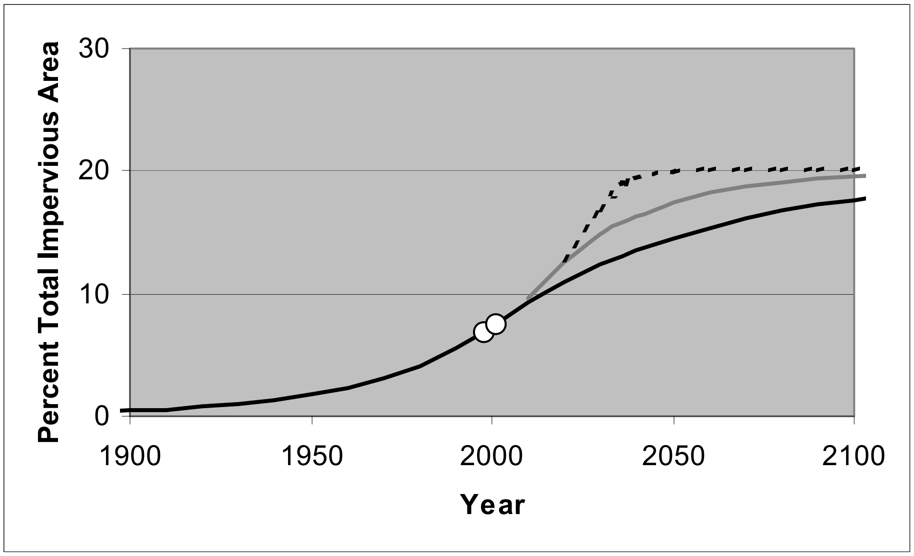

Figure 7. S-curve models of percent total impervious area in the Snohomish River basin with transition to limited growth in 2001 (black line), 2015 (gray line) and 2030 (dashed line).

This simple modeling approach makes it easy to construct and evaluate alternative future scenarios. It can be used to do "what if" analysis by changing the long term limit or the transition year and seeing what happens. Local governments and watershed planning groups can use it to set near term goals that are consistent with their long-term vision for the future.

Given a long-term goal, the S-curve model can even assist with adaptive management. Actual conditions can be monitored and compared to the model. If actual conditions are not consistent with the model, additional actions could be taken and a new scenario could be developed to show a revised path toward the desired long-term goal.

Areas for Future Research and Development

This simple approach has the potential to help citizens and governments make decisions that more explicitly consider the potential long-term consequences. Similar models can be developed for a variety of indicators. This section describes some steps that can be taken to validate and extend these simple models.

The TIA examples were constructed using limited data at a coarse scale. The graphs were created by fitting simple equations to just two data points, and there was no validation beyond looking at the general shape of the curve. While this approach provides important results, it would benefit from extending the time period for the analysis and using a finer geographic scale. The required satellite images are available from the mid-1980s on.

Another approach would be to study a time series of historical photos showing an area going from undeveloped to intensely developed. Aerial photos are available for a longer period than satellite images. The photos could be analyzed using image processing software to estimate the TIA at each point in time. The data could be plotted and compared to the S-curve, and the model could be refined as needed to more closely match the observed changes.

One weakness of this approach is that it is not spatially explicit. With the exception of the protected areas that were set aside, it does not provide insight into where the new impervious areas will be located. Knowing that the basin will have thousands more acres of impervious area is not particularly useful without any knowledge of where it will go.

The model could be extended to operate at a finer geographic scale and have the results rolled up to the basin, or even to the Puget Sound scale. The Snohomish River basin has land uses ranging from wilderness areas to high intensity urban development. Treating farms and national forest land differently turned out to be useful in estimating a long-term limit. Dividing the basin further would allow different long-term targets and initial conditions in the different areas. The analysis could be done for each of the subwatersheds for which the 2001 TIA data has already been analyzed. The resulting projections for each subwatershed could then be combined to get an aggregate model for the entire basin.

Growth management planners will want to divide the landscape into rural and urban areas and more specific land use categories. The existing boundaries and zoning might not be a sound basis for long term forecasting because they change, but putting several alternative future boundary scenarios into the model could help contribute to informed decisions. This would also allow alternative future maps to be developed, showing visually what the future of the basin would look like under different scenarios.

Spatially explicit models that predict where new development occurs based on other factors could extend the usefulness of this approach from long term visioning to more explicit long term planning, and ultimately to specific land use decisions.

It was mentioned earlier that similar models could be used for other variables of interest. Watershed and regional planning groups might wish to develop alternative future scenarios and examine them using several different indicators. It would be useful to develop a set of indicators that can be modeled with equations similar to those in this paper. For some variables, such as number of acres of wetlands in a watershed, the model needs to be turned upside down. The historical trend has been a loss of wetlands, and the long-term goal might be a minimum area instead of a maximum area.

There may be situations where the desired long-term target has already been exceeded and restoration is required. This is called “overshoot,” and it is common in natural systems. It could be applied to TIA in areas where it is reasonable to remove pavement and restore open spaces. It is likely to find even more application to variables that are less permanent than pavement, such as the number of exceedances of a water quality threshold or the amount of water withdrawn from rivers in an overappropriated basin. Turning it upside down, as was done for the S-curve, would allow it to be applied to salmon populations that have been reduced below a target level or to the number of days per year when air quality is above a certain threshold.

For the results to be useful, the model should be linked to the values and objectives that people use to make decisions. This paper focused on developing and demonstrating the model, and it did not attempt to describe the ecological consequences associated with different levels of TIA. Those consequences would need to be carefully considered to construct an alternative future scenario that could be described and evaluated based on the values, goals and objectives of a group. It may be useful to develop a set of appropriate variables that could be modeled consistently across the region and to describe their relationship to social values in advance of any specific application.

Conclusions
Figure 8 graphs the exponential model and the S-curve model together for comparison, and this time it assumes a practical limit of 20% TIA for both curves. The truncation of the exponential curve is a reminder that the current rate of growth in total impervious area is unsustainable. If the amount of TIA keeps increasing at the same annual percentage rate, no matter how low the actual rate is, it will eventually reach the limit and there will be an abrupt change. If development of new impervious areas continues along the current trend, all the available land in the Snohomish River basin will be covered by the year 2036 and there will be no new areas to develop.

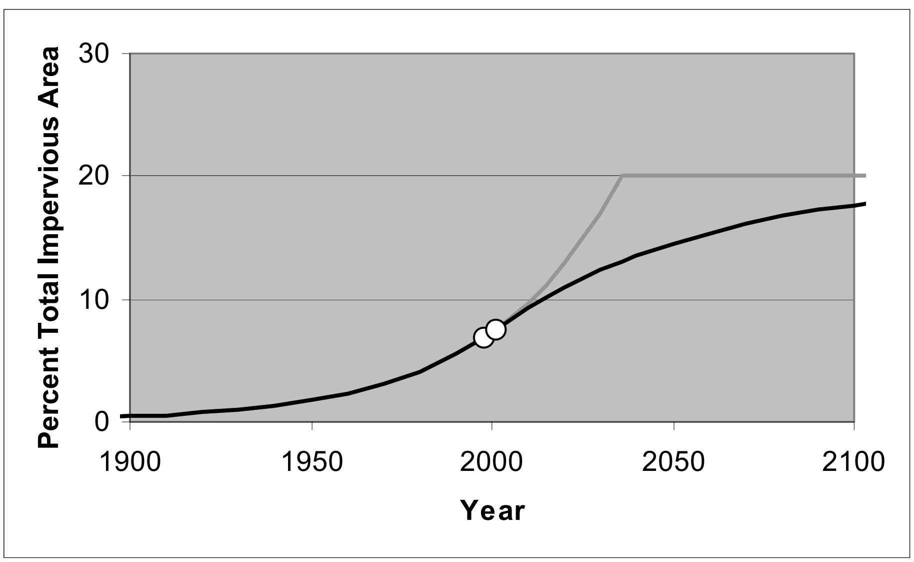

Figure 8. Exponential (gray line) and S-curve (black line) models of percent total impervious area in the Snohomish River basin, assuming a long-term limit of 20%.

The S-curve model shows one trajectory that avoids an abrupt transition by gradually slowing the rate of growth in the future. It also shows that the more time that passes before the rate goes down, the more severely growth will have to be curtailed in the future.

The same model could be applied to other variables of interest that have limits, such as the filling of wetlands, hardening of shorelines or appropriation of water. While the model does not predict exactly where and when change will occur, it does allow alternative future scenarios to be developed and compared. It provides a simple graphical view of the amount of change that is needed or allowed to achieve a preferred future condition. It even supports adaptive management by providing a reference for comparison with actual monitoring results to determine whether additional actions are needed to stimulate or limit change.

Simple models such as this may help the public, as well as public servants, recognize the long-term ecological consequences of local government planning decisions. If the projection of current trends reveals an undesirable scenario, it may motivate consideration of alternative future scenarios which, in turn, may lead to decisions that more fully reflect social values for protection of natural resources and ecological systems that change slowly over long periods of time.

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