Gateway Blueprint Model Workshop 2005

Hydrological and Water Quality Modeling in the St. Louis Region

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Abstract:

Hydrologic and water quality impacts can be quantified by combining a spatial urban growth model and a hydrological and water quality model. A dynamic hydrological and water quality model is capable of capturing the temporal pattern of streamflow and water quality variables such as sediment loading or nutrient concentration. This model can provide watershed planners information on how future land use change can effect flooding in the region and which watersheds (and sub-watersheds) are facing the greatest risk to water quality for a variety of pollutants. This study shows the potential effect of future urbanization in the Richland Creek watershed in St. Clair County. Overall, the impacts of urban growth in the region on hydrology and water quality may not be significant in terms of mean pollutant levels, but may be substantial in terms of maximum values. However, the impacts are different in different locations of the watershed due to the concentration of development in the upstream area. The future urban growth simulated by LEAM can increase the risk of flooding and lead to increased pollutant yields in selected parts of the watershed.

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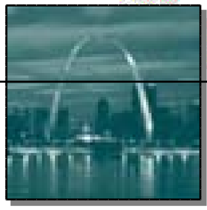

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Introduction

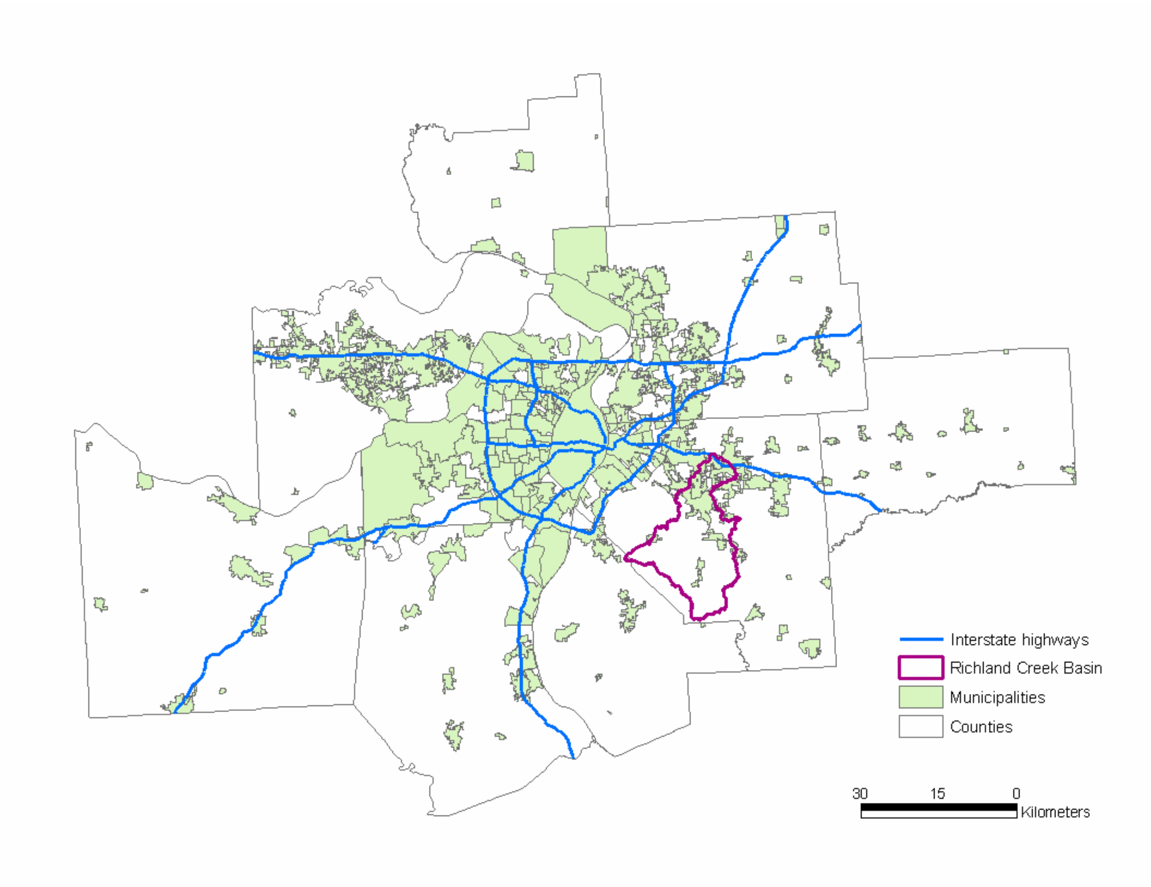
It is well known that land use change modifies basin hydrology and related water quality in various ways. Such impacts can be quantified by combining a spatial urban growth model and a hydrological and water quality model. A dynamic hydrological and water quality model is capable of capturing the temporal pattern of streamflow and water quality variables such as sediment loading or nutrient concentration. The new LEAMwq presents more detailed analyses of land use change impacts on water resources for a specific watershed in the St. Louis region. This model can provide watershed planners information on how future land use change can effect flooding in the region and which watersheds (and sub-watersheds) are facing the greatest risk to water quality for a variety of pollutants. The model can also be used to estimate the impacts of various conservation strategies to improve water quality and reduce the risk of flooding.

Method

The new LEAMwq features integration of LEAM and HSPF (Hydrological Simulation Program – FORTRAN). HSPF is a semi-distributed dynamic hydrological and water quality model supported by the U.S. Environmental Protection Agency. It is embedded in BASINS (Better Assessment Science Integrating Point and Nonpoint Sources), which processes GIS data for HSPF.

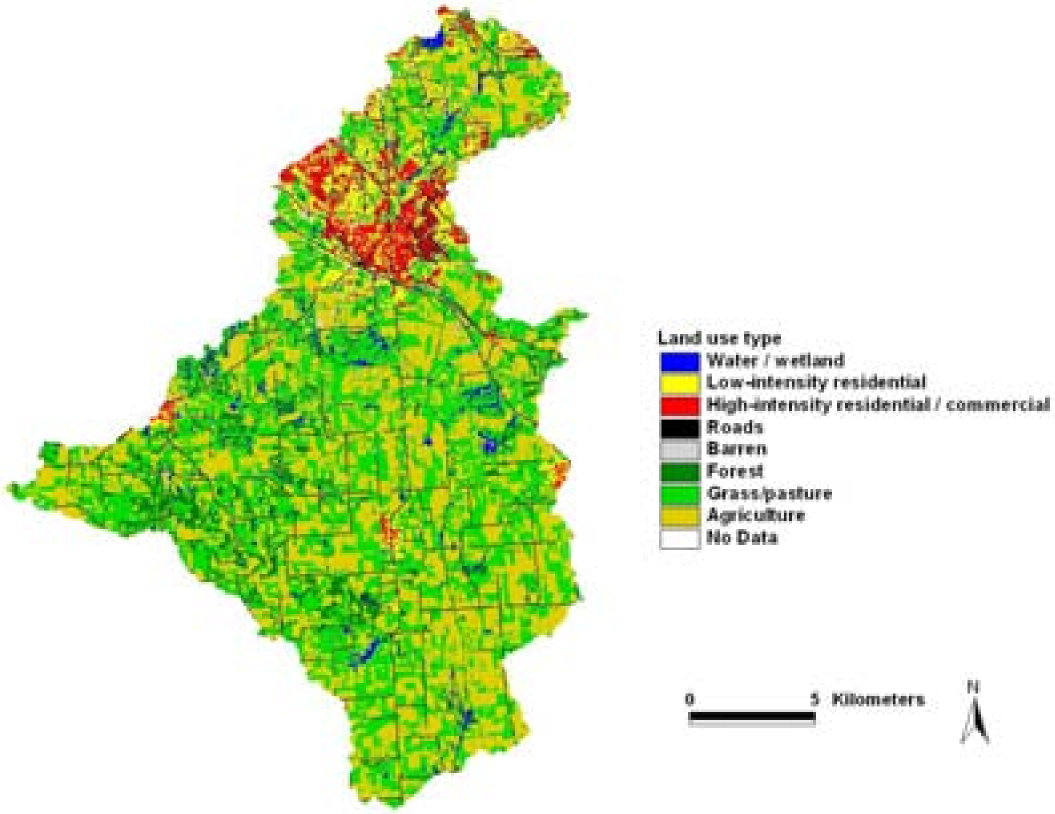
The Richland Creek Basin in Illinois was selected as a study site. The Richland Creek Basin (RCB) is located in St. Clair County and has a drainage area of 334km^2. It is a tributary of the Kaskaskia River, which eventually joins the Mississippi River at the southern tip of Illinois. The Kaskaskia River is the second largest river system within Illinois, and has been an important natural feature in Southwestern Illinois throughout recorded history.

Figure 1. Location of the Richland Creek Basin



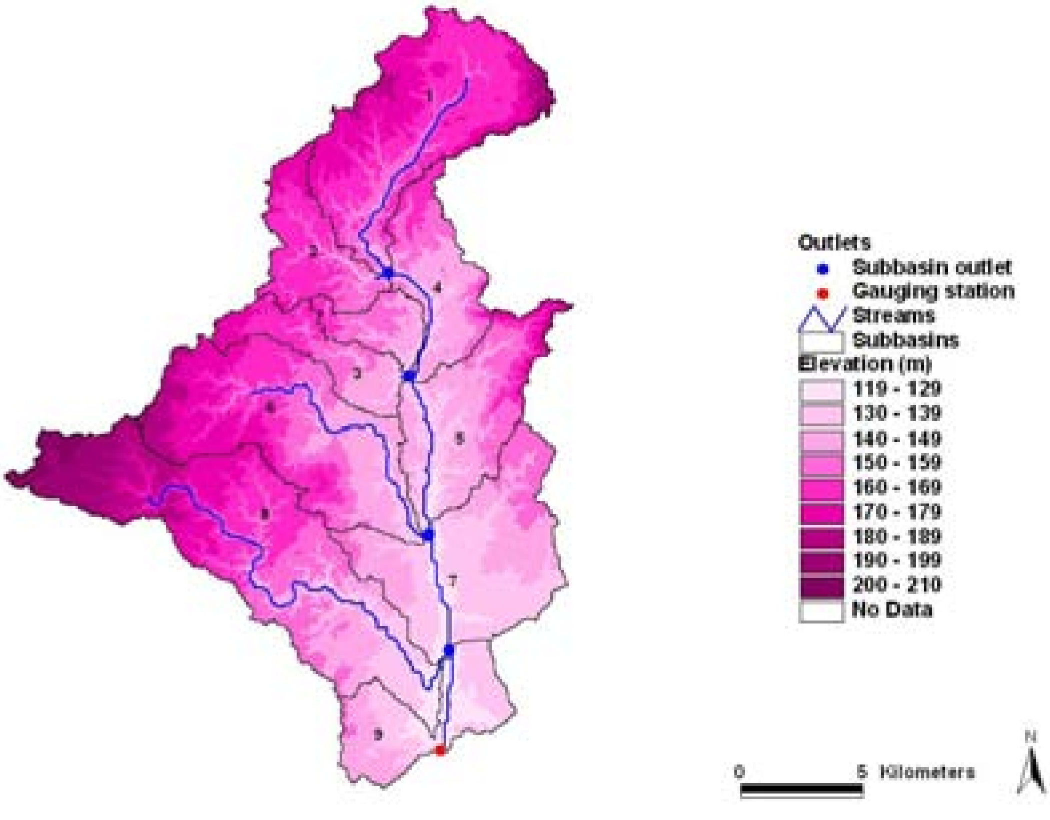
HSPF simulates streamflow and several water quality variables including sediment loads, nutrient concentration and water temperature at any point in a watershed using the hourly meteorological data set and land use data. The 2000 land use map was produced by combining 1992 National Land Cover Data (NLCD) of the U.S. Geological Survey and 1999-2000 Illinois land cover map produced by Illinois Department of Agriculture and reclassifying the land cover categories. This map was used to create an HSPF project that represents the current land use condition.

Figure 2. Land use map as of year 2000



Subbasins are automatically delineated based on the elevation of the area in BASINS environment. BASINS also calculates subbasin attributes such as area, mean elevation, mean slope and stream length and saves them under a separate attribute table. Such information is then exported to the HSPF model.

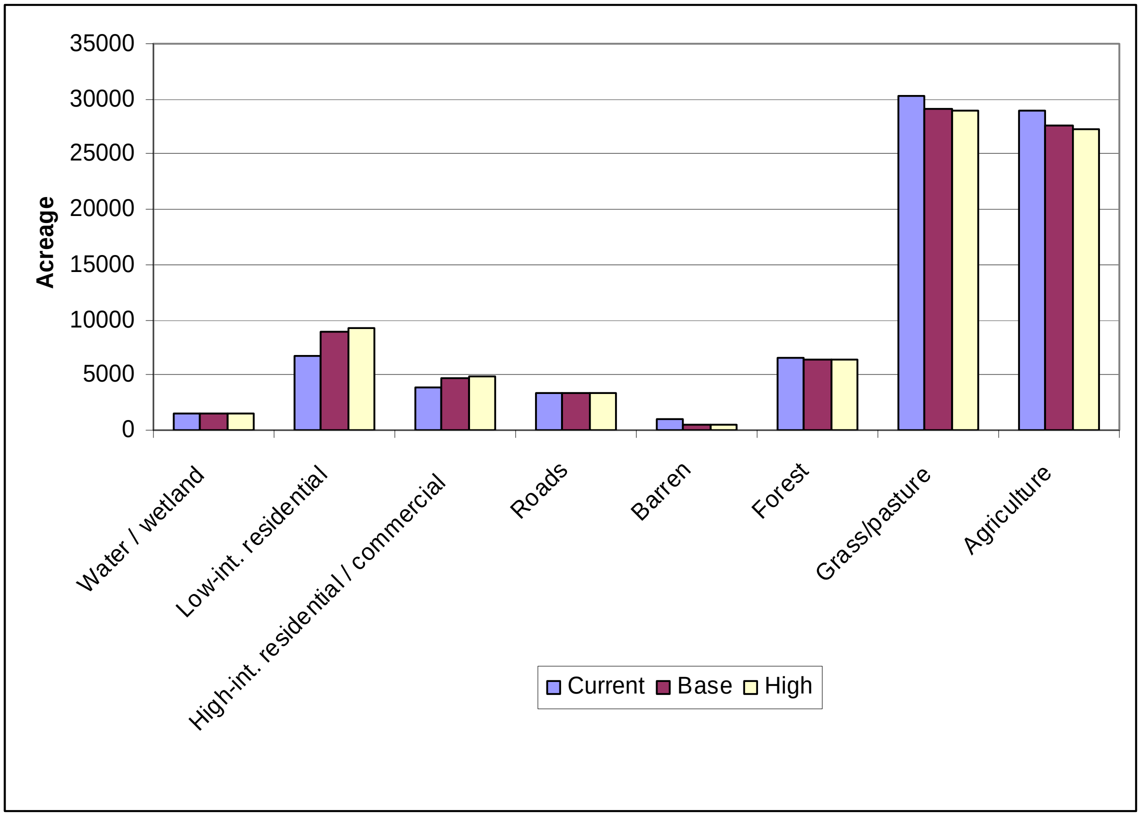
Figure 3. Sub-basins delineated based on elevation



The model was run with the current land use map as of 2000 and future land use maps produced by LEAM under Base and High economic growth scenarios. Separate HSPF projects were created to accommodate each land use map and named as RICHLAND (current), RICHBASE (Base) and RICHHIGH (High). The variables simulated by HSPF are streamflow, sediment loads and Orthophosphorus (PO_4) concentration.

LEAM projection of future land use show that low-intensity residential, high-intensity residential/commercial lands are projected to increase while barren, forest, grass/pasture, agriculture lands decrease.

Figure 4. Projected future land use changes under Base and High scenarios



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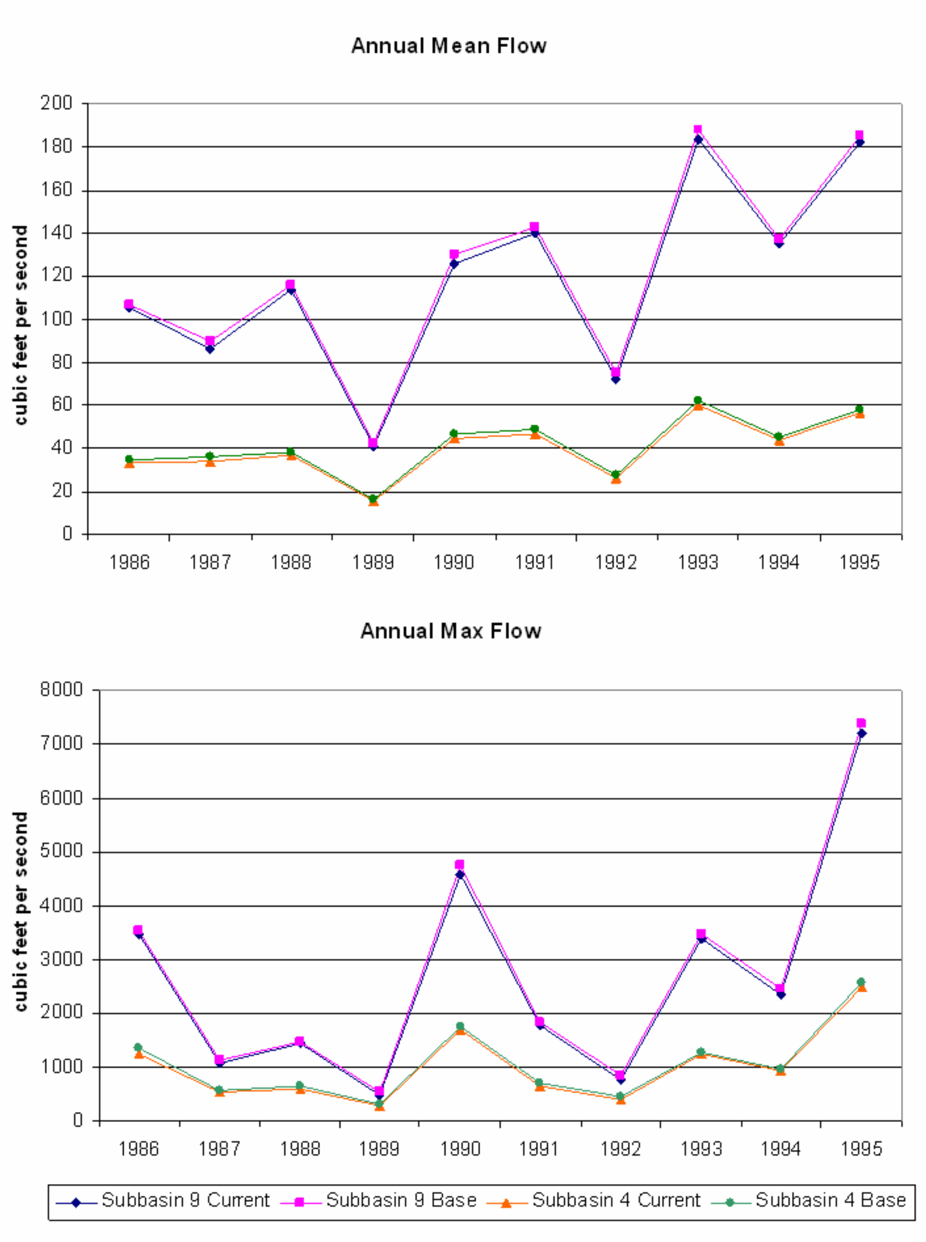
Results

Figure 5 shows the mean (upper) and maximum (lower) annual streamflow from two different subbasins with different land use conditions. Subbasin 4 is located relatively upstream and is more urbanized while Subbasin 9 is located downstream and is mostly agricultural land. The streamflow over the 1986-1995 period (time period of meterological data set) was compared between current land use condition and LEAM base scenario results. The high growth scenario results are not displayed since they are almost same as Base scenario results. Streamflow is predicted to increase slightly in both locations, but annual maximum flow is predicted to increase up to 14% under 1989 and 1992 meteorological conditions. Considering that the magnitude of maximum flow is estimated to be dozens of times larger than the mean flow, the impact of urban growth on maximum flow can be substantial. Subbasin 4 tends to show larger percent increases than Subbasin 9. It implies that the effect of development upstream can diminish at the outlet of the watershed and shows the utility of HSPF model in identifying the area for more attention.

Figure 5. Changes in streamflow due to land use change



As indicators of extreme streamflow events, Q5 (95th percentile) and Q1 (99th percentile) daily flows were determined from the 1970-2003 flow records as 450 and 1740 ft^3/s respectively. The number of days with mean flows over those values at the outlet of the watershed was compared under current and future conditions based on the HSPF simulation over the period of 1975-1995. Q5 shows gradual increases with urban growth, from 310 days to 327 under base scenario conditions and 335 days in the high growth scenarios. This means it is likely that the Richland Creek Watershed will experience such high flows more often. On the other hand, Q1 flow shows no change in frequency, but its magnitude is likely to increase as shown in the previous figures.

Figure 6. Frequency of extreme flows

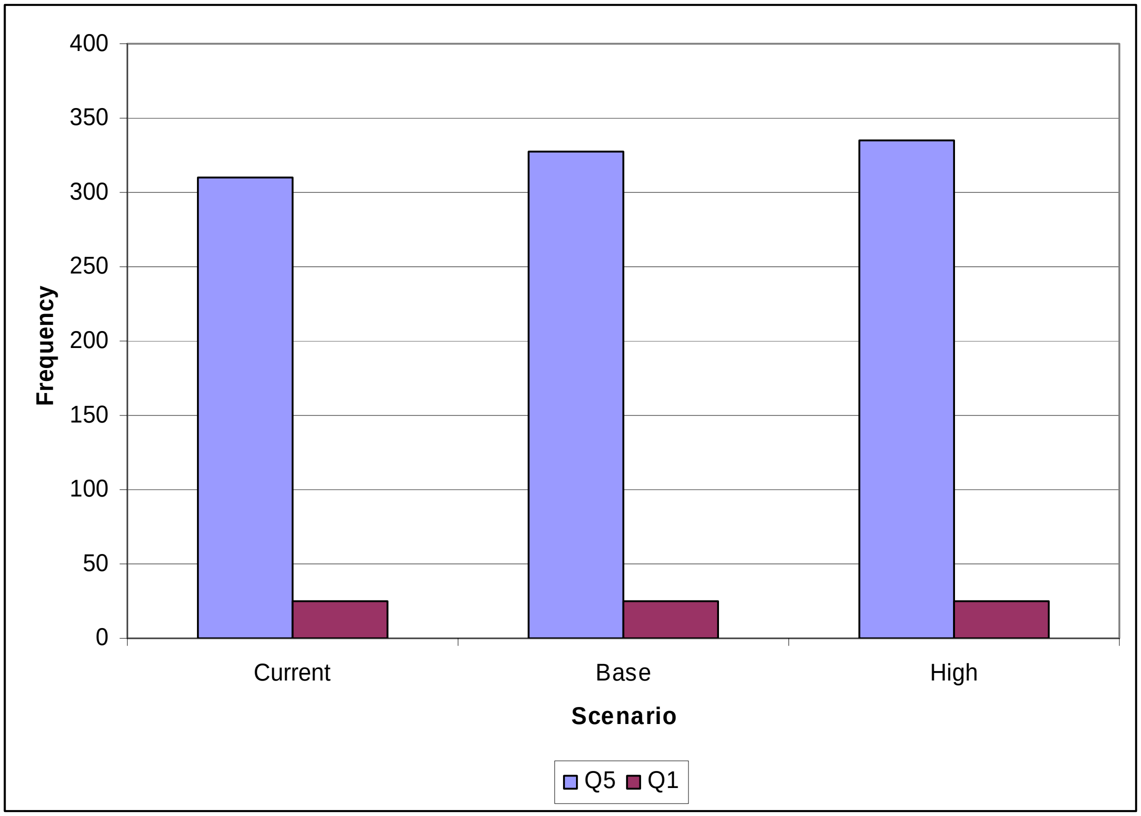
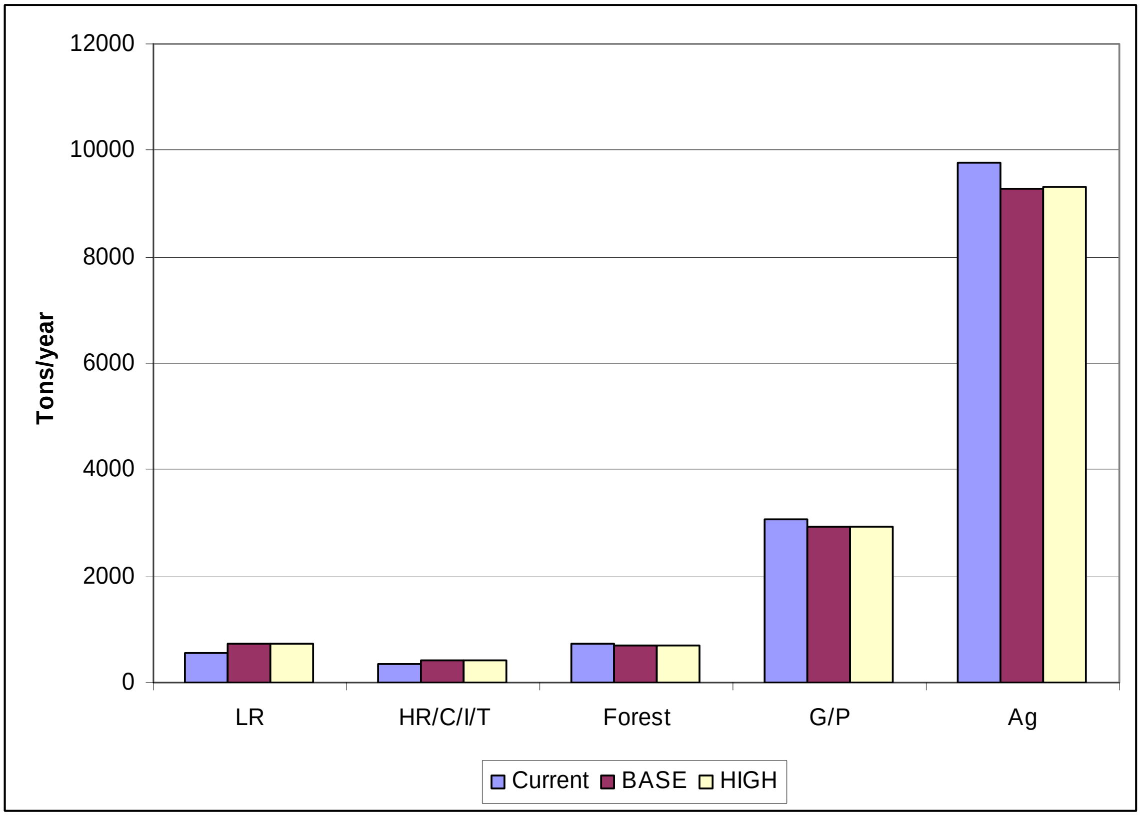


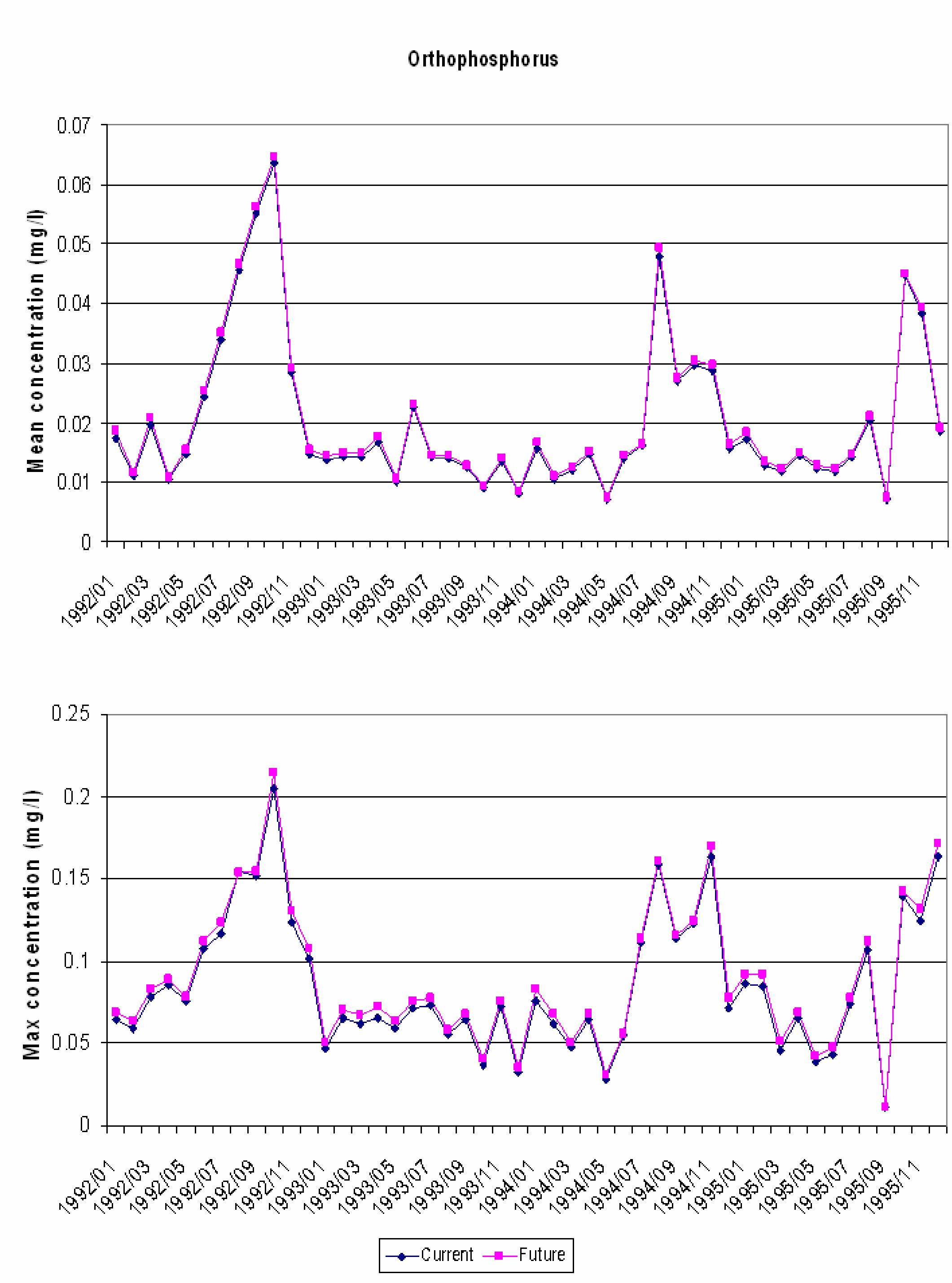
Figure 1 shows the mean annual sediment loads from different land use types under different land use conditions over the period of 1992-1995. It shows that agricultural land (Ag) is the most important source of sediment, and the sediment from agricultural land is predicted to decrease by 4.9% in the future. Sediments from low-density residential land (LR) and high-density residential, commercial, insdustrial and transportation (HR/C/I/T) are predicted to increase 33.7% and 22.7% respectively. However, total sediment is predicted to decrease by 2.5%. Consequently, based on this analysis, total sediment loads will not be significantly affected by land use change.

Figure 7. Annual sediment loads



Future Orthophosphorus Concentrations were also estimated in the model. It is predicted that monthly mean PO_4 concentration will increase insignificantly while monthly maximum concentration shows a bit more increase (Figure 8). It should be noted that the magnitude of maximum concentration is several times higher than mean concentration. PO_4 concentration tends to be higher during summer and autumn month when streamflow is generally low and lower during winter and spring when streamflow is generally high. PO_4 concentration tends to increase with larger percentage when it is low (winter and spring). Overall, PO_4 concentration is predicted to increase in the future as well as streamflow, which means that the amount of PO_4 exported to streams will be even more in the future.

Figure 8. Monthly Orthophosphorus Concentration



Conclusion

The new 'dynamic' LEAMwq provides insight into the changes in water quantity and quality due to land use changes at various spatial and temporal scales. The initial application of LEAMwq to the Richland Creek Basin found that:

- the overall impacts of urban growth in the region on hydrology and water quality may not be significant in terms of means, but may be substantial in terms of maximum values
- the impacts are different in different locations of the watershed due to the concentration of development in the upstream area
- the future urban growth simulated by LEAM can cause more risk of flooding and increased pollutant yield in selected parts of the watershed

Further water quality analysis is needed in the region to get a better understanding of where flooding and water quality will become bigger issues as urbanization continues. The next steps include:

- calibration of water quality simulation with observed water quality data,
- more analysis of impacts in different sub-basins, and
- simulation of more water quality variables.