Epilogue

While we were developing the Potomac Treatise, many scientific, technical, and engineering issues were noted. Most of the answers to these issues are beyond the scope of our treatise. Nevertheless, the following water quality issues need to be addressed.

For the Upper Potomac River Basin, our analysis suggests:

1. The mean annual stream flow of the Upper Potomac River above Washington, DC appears to be increasing—at the same time as the percent of forestlands have increased. **This is a counterintuitive observation**. A rigorous statistical analysis of annual river flow trends is needed to confirm this increase. What are the physical, chemical, and biological processes causing this increase in annual flow?

2. Even more important is the increase, since the 1950s, in the intensity and frequency of spring runoff pulses. The number of months in which the mean monthly river flow was over 40,000 cfs has increased from five months, during the first half of the 20th century, to 21 months since the 1950s. Reforestation appears to not have had the expected positive impact. A rigorous statistical analysis of monthly and possibly daily trends for the Potomac River gauging station above Washington, DC, including one for the Point of Rocks stream flow gauging station, is needed. What are the physical, chemical, and biological processes causing these increases in spring pulses?

3. Prior to the 1950s, there were only five years in which the Upper Basin maximum monthly nitrogen loadings were over 100 kg/km^2/month during the first five months of the calendar year. From 1950 to 2004, there were 28 years in which the Upper Basin maximum nitrogen monthly loadings were over 100 kg/km^2/month during the first five months of the calendar year. The number of spring pulses, which are the major mechanism for replenishment of the surface nutrient pools of the Lower Estuary, have increased in intensity and frequency. Can these pulses be reduced in intensity and frequency by small U.S. Soil Conservation impoundments on first- and second-order streams? Can denitrification be stimulated and phosphorus retention be increased in these small impoundments? Dr. Eugene Odum, a world-renowned ecologist, has stated that **pulse stability** is required to maintain a healthy estuarine ecosystem. Has the increase in the intensity and frequency of the spring pulses had a negative impact of the ecology of the Potomac Estuary?

4. About 7% of the phosphorus, 19% of the nitrogen, and 61% of the potassium landscape loadings to the Upper Basin from fertilizer, animal waste, municipal wastewater, and air deposition is exported out of the watershed by the Potomac River. ***Where have the remaining percentages of nutrients gone?*** Can we mass balance the inputs and outputs of the Upper Potomac River Basin and its sub-basins? Are we reaching nitrogen and/or phosphorus **saturation** in the agricultural lands? What do we need to do about possible increases in groundwater nutrient concentrations, as suggested by the USGS?

5. Of the 25 major watersheds of the Middle Atlantic and Northeast USA, the Upper Potomac and the Susquehanna have the lowest phosphorus export percentages (Potomac 7.5% and Susquehanna 6.6%). Other watersheds were about 18%. What is different about the Potomac and Susquehanna watersheds? How good are our watershed models? Can we predict these differences?

6. Of the eight major sub-basins of the Upper Potomac, the Shenandoah has the lowest nitrogen and phosphorus export percentage. What is different about the Shenandoah Watershed? Does unconfined beef production in the Shenandoah Watershed have a lower riverine nutrient export flux than confined dairy cattle production, such as in the Conococheague Watershed?

7. Recent nutrient water quality data from the West Virginia fixed stations suggest that there have been no significant increases in nutrients as a result of large increases in poultry production in the Headwaters of the South Branch and Cacapon sub-basins. Is there a “lag” time between landscape loading and riverine export? Are the groundwater nutrient concentrations increasing?

8. Data from the past 40 years suggest that the percent of nitrogen and phosphorus landscape loadings exported from the Upper Basin ranges from 10% for nitrogen and 2% for phosphorus at low flows, to 50% for nitrogen and 23% for phosphorus at high flows. Can our current watershed models predict these impacts of flow? Is a more fundamental understanding of the processes controlling export fluxes needed?

9. Agricultural landscape loading, the largest source of nutrient inputs, has increased exponentially over the past century, resulting in an exponential riverine nitrate (or phosphorus) concentration versus landscape nitrogen (or phosphorus) loading relationship. Can existing watershed models incorporate exponential relationships?

10. A reduction in animal waste loading inputs of more than 60% is required to improve the low summertime dissolved oxygen concentrations of the bottom waters of the Lower Estuary. To do this, quantum reductions in nitrate export fluxes from animal waste are needed. Is the solution not in best management practices (BMPs), but in advanced utilization technologies (AUTs)? In wastewater treatment, we have gone from primary, to secondary, to advanced wastewater treatment (AWT) technologies. Is the same progression of technology development needed for the future management of animal waste?

11. Riverine potassium concentrations have increased, while silica concentrations have remained level over the past +60 years. Both are essential nutrients. Potassium is an ideal stable tracer for nitrogen. Should future studies include the role of potassium and silica in the over-enrichment of the Potomac River and its Estuary?

For the Potomac Estuary, our analysis suggests:

1. The bottom waters surrounding the Ragged Point and Point Lookout stations have been anoxic, around 1.0 mg/l and less, during the summer months for the past 50 years. **There appears to be sufficient light penetration and nutrients in the spring surface pool to produce plankton blooms every year in the Lower Estuary. These blooms produce enough oxygen-consuming organic matter to drive the DO in the bottom waters anoxic every summer.** What concentration of DO in the bottom waters will the current nutrient reduction program achieve? What about the need for stable pulses as suggested by Dr. Odum?

2. Total TP loadings to the entire Potomac Estuary have decreased from a high of 6,000,000 kg/yr in the late 1960s to about 2,670,000 kg/yr in the 1980-2004 period. While the surface TP concentrations have decreased throughout the Estuary, there has been no improvement in the bottom water DO in the Lower Estuary. Why has there been no improvement? Will the amount of phosphorus release from the sediments decrease over time? How long?

3. During the summer months when the Ragged Point Station bottom waters went anoxic, the Ragged Point Station surface DIN pools were depleted and surface TP pools were the largest. When the bottom waters do go anoxic, the surface TP in July and August often doubles in concentration compared to the spring concentration. Most of this increase in the surface TP pool is from the diffusion of phosphorus from the anoxic bottom waters and sediments. There was also a large summer increase in surface silica concentration when the bottom waters went anoxic. Can phosphorus concentrations from the Upper Basin be reduced enough to reduce the spring plankton bloom? If not, can DIN be reduced?

4. There were six water quality surveys of the Potomac Estuary during 1912 and 1913. The most useful survey was the cruise on September 21-22, 1912. There were two areas of low DO bottom waters in the Washington, DC and Ragged Point areas. There were sufficient nutrients to cause the bottom water DO in the three stations in the Ragged Point area to be hypoxic (about 2.0 mg/l in mid-late September). Was the low DO in the bottom waters in the Ragged Point area in September 1912 **a natural occurrence**? It is important to note that the 1912 DO survey was in response to reports of fish and shellfish mortality occurring at the mouth of the Potomac Estuary and other rivers flowing into the Chesapeake Bay, as well as in other tidal waters. It should also be noted that in the 1910s, there were no major power plants, pesticides, commercial fertilizers, chemical plants, etc. in the Potomac Basin. Can the Chesapeake Bay water quality model predict these historic low DO concentrations? If not, does the model need to be improved?

5. The September 1912 survey data indicated that two sampling stations in the Chesapeake Bay near its confluence with the Potomac Estuary had bottom DO levels over 5.0 mg/l. Will improvements in DO in the Chesapeake Bay also result in improvements in the Lower Potomac Estuary and vice versa?

6. From the summer of 1998 to the summer of 2002, the annual flow of the Potomac River was 6,800 cfs—about a 62% reduction from the previous three years. From January 1996 through June 1998, the average TN and TP loadings were 44 million kg/yr and 6 million kg/yr respectively. The average TN load from July 1998 to July 2002 was 13 million kg/yr (a reduction of 66%), while phosphorus was 1 million kg/yr (a reduction of 60%). For the four years of dramatically reduced inputs, the TN loadings were around 100 kg/km2/yr. There appears to have been sufficient light penetration and nutrients in the spring surface pool to produce the plankton blooms. These blooms were able to produce enough oxygen-consuming organic matter to drive the DO in the bottom waters anoxic in June. However, in July and August 2002 there appears to have not been sufficient nutrients diffusing from the anoxic bottom waters to supply the nitrogen, phosphorus, and silica needs of the plankton in the surface pool. The phytoplankton, therefore, were not able to produce enough oxygen-consuming organic matter to keep the DO in the bottom waters anoxic. Thus, the bottom water DO increased to over 2.0 mg/l in July and August 2002. This suggests that **if the spring pulses are less than 100 kg/km^2/month**, there will be sufficient replenishment of nutrients in the spring surface pool to allow the plankton to produce **enough oxygen-consuming organic matter to drive, but not keep, the DO in the bottom waters anoxic in the late summer months**. Are our analysis and interpretation correct?

7. One of the best tests of the predictive capability of the watershed model linked to the Bay water quality model is to simulate the 1995-2005 conditions which were three years of high flow followed by four years of drought followed by three years of above average flow conditions. Can the watershed model predict the nutrient loads under all the conditions? Can the Bay water quality model predict the nutrient dynamics and resulting bottom water DO in the Lower Estuary?

Finally, it is somewhat astonishing that there is neither a federal, state, nor academic institution on the shores of the Potomac River or its Estuary devoted to a holistic understanding of the long-term water quality management requirements of the Potomac River Basin and its Estuary. A *Washington Post* article dated January 29, 2007 reported that it might cost over $6 billion to clean up the Chesapeake Bay. With these high cost projections, it is imperative that we have scientific, technical, and engineering answers to the questions posed above. We also need a mechanism—such as a Potomac Water Quality Institute—that is dedicated to the scientific pursuit and holistic solution to these water quality management issues.