MANAGEMENT APPLICATIONS

A holistic management approach must be accelerated to remediate environmental problems in BB-LEH associated with nutrient enrichment due to ongoing development and land use-land cover changes in the watershed. Multiple corrective strategies should be applied concurrently, such as improved stormwater control systems (e.g., currently stormwater basin upgrades are targeting 10 of ~2700 stormwater basins), implementation of best management practices in the watershed, open space preservation, fertilizer controls, soil restoration, and education programs that explain to the public how and why these strategies are important and necessary for the protection of BB-LEH. Management of the watershed must also examine ways to minimize the creation of impervious surfaces, compacted soils, and sprawl, while concurrently preserving natural vegetation and landscapes. A well-coordinated and holistic management plan is critical to improving the ecological condition and resources of the estuary. This is a long-term approach to remediate the eutrophication problems in the estuary.

A total maximum daily load (TMDL) for nitrogen and phosphorus is also a necessary element to effectively mitigate the eutrophic condition of the estuary. Application of a TMDL should be pursued concomitantly with the other management approaches noted above. It is necessary to respond aggressively at this time to nutrient loading from the watershed because of the severity of the eutrophication problems in the estuary, which may become intractable if they are not remediated in the short term.

Results of the Index of Eutrophication applied in this study indicate that eutrophication of the estuary is greatly worsened by increasing total nitrogen loading and total phosphorus loading. Once loading increases beyond 2000 kg TN km^{-2} yr^{-1} or 100 kg TP km^{-2} yr^{-1}, as is the case in the north segment of the estuary, eutrophication condition reaches a new, lower steady state of poor condition. We therefore recommend a strict limit on nitrogen and phosphorus loads to 1500 kg TN km^{-2} yr^{-1} and 75 kg TP km^{-2} yr^{-1}as a starting point of control to remediate eutrophication of the estuary.

Reducing the fraction of urban area that is covered by turf will likely reduce the loads of nitrogen and phosphorus to BB-LEH. This is because concentrations of total nitrogen are substantially higher for developed turf areas than for developed non-turf areas, which in turn, are higher than those for undeveloped areas. Concentrations of total phosphorus also are higher for developed turf areas than for developed non-turf and undeveloped areas.

Better management of turf areas—for example, reducing the amounts of nitrogen- and phosphorus-containing substances applied to turf areas—will likely reduce overall loads of nitrogen and phosphorus. Reducing the volume of stormwater directly discharged to streams will also reduce the runoff component of nitrogen and phosphorus loads, and will likely reduce the total loads to BB-LEH.

Much of the land in the southern portion of the watershed is protected from intense development. Based on previous investigations in the watershed and the analysis of existing data as part of this study, future increases in development in the central and south segments will likely lead to higher concentrations and loads of nutrients in the streams located in those areas, thereby increasing nutrient inputs to the estuary.

Runoff accounts for a greater percentage of flow in the highly developed basins, and a smaller percentage of flow in the less developed basins. The total amounts of runoff and the runoff contribution of nitrogen and phosphorus loads will likely increase with additional urban development. The baseflow contributions of nitrogen loads, which are generally greater than the runoff contributions, also are strongly associated with urban land and will likely increase with increasing urban development.

A more complete understanding of nutrient cycling in the watershed could be achieved with the use of additional, targeted water-quality monitoring in conjunction with a watershed water-quality model that considers in-stream processes, shorter time steps, and that targets individual streams and reaches.

CONCLUSIONS AND RECOMMENDATIONS

BB-LEH is an estuary that has undergone significant ecological decline, as evidenced by the increasing eutrophication of the central and south segments since the 1990s ($P < 0.05$) and an even worse eutrophication condition documented for the north segment. Collectively, the direct relationship between nutrient loading from the watershed and estuarine nutrient concentrations, the degradation of an array of biotic indicators, and the relationship between nutrient loading and the Index of Eutrophication supports the conclusion that BB-LEH is a highly impacted estuarine system.

Total nitrogen loading and total phosphorus loading have caused substantial degradation and eutrophication of BB-LEH. The condition of the estuary has progressively worsened over time for both nitrogen and phosphorus (Figures 3-31, 3-36, and 3-39) resulting in an array of bottom-up impacts evident in nuisance and toxic algal blooms, declining eelgrass beds, and other parameters of change. The rate of decline of eelgrass is related to nutrient loading and associated symptoms of eutrophication. Overall, eutrophication is greatly worsened by increasing total nitrogen loading and total phosphorus loading. Once loading increases beyond 2000 kg TN km^{-2} yr^{-1} or 100 kg TP km^{-2} yr^{-1}, as is the case in the north segment of the estuary, eutrophication condition reaches a new, lower steady state of poor condition.

Overall, water quality condition has been declining throughout the estuary since the early 1990s. Total nitrogen loading and total phosphorus loading scores in index calculations were lower (more degraded) during 2003-2010 than in previous years, indicating a worsening condition. Loading for both nutrients is greatest in the north segment where environmental condition is most impacted. While nutrient loading has been linked to increasing eutrophication of the estuary, specific levels of total nitrogen

loading and total phosphorus loading as tipping points for ecosystem decline have not been determined.

While no nutrient criteria have been established for the BB-LEH Estuary, one remedial approach is to establish a nutrient standard based on cause-and-effect relationships, notably making accurate measurements of variables representative of nutrient loading (causal variables) in the watershed and those based on biotic response (response variables) in the water body. In the case of response variables, a suite of key variables which permit integrated assessment of biotic communities and habitats will provide more accurate data on ecosystem condition and nutrient impacts than can a single response variable. Integrated response variables may not only include biotic variables, such as phytoplankton, macroalgae, and seagrass, but also physicochemical variables, such as dissolved oxygen and total suspended solids. The complete array of causal and response variables used in this project are provided in Components 2 and 3 of this report.

We recommend a two-pronged management approach to address the eutrophication problems in BB-LEH. First, a TMDL for nitrogen and phosphorus should be established for the system, limiting total nitrogen and phosphorus loads to 1500 kg TN km^{-2} yr^{-1} and 75 kg TP km^{-2} yr^{-1}.

In addition, an array of other managment strategies must be aggressively applied concomitantly with a TMDL. These include measures that improve stormwater control systems, best management practices in the watershed, open space preservation, fertilizer controls, soil restoration, and support education programs that explain to the public how and why these strategies are important and necessary for the protection of BB-LEH. Management of the watershed must also examine ways to minimize the creation of impervious surfaces, compacted soils, and sprawl, while concurrently preserving natural vegetation and landscapes. A well-coordinated and holistic management plan is critical to improving the long-term ecological condition and resources of the estuary.