An Economic Assessment of Water Quality Improvement BMPs for the Eagle Mountain Lake Watershed

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Abstract

The objective of this assessment was to identify the most cost-effective means of reducing (and/or preventing) total phosphorus (TP) inflows into the Eagle Mountain Lake from a comprehensive set of Best Management Practices (BMPs). Additionally, the reduced total nitrogen (TN), and sediment inflows resulting from adoption of these BMPs was also calculated. To achieve the desired water quality improvements, management consulting engineers indicated that the collective assortment of BMPs needed to reduce TP inflows by approximately 30 percent below current levels. During 2009-2011, Texas AgriLife Extension Service and Texas AgriLife Research scientists, in conjunction with Tarrant Regional Water District (TRWD) managers, NRCS professionals, and others worked to identify a portfolio of BMPs capable of contributing to such reductions. The economics component of this project consisted of integrating the simulation modeled results of nutrient and sediment inflow dynamics with the associated costs of BMP implementation. This BMP cost analysis provides a basis for the evaluation of a suite of BMPs that could be expected to result in meaningful TP inflow reduction. The final task was to identify the cost-effective combination of BMPs that could be expected to achieve the management target of a 30 percent reduction in TP inflow into the Eagle Mountain Lake over a 50-year project period.

Introduction

The Tarrant Regional Water District (TRWD) operates five major water-supply reservoirs in the Fort Worth-Dallas area - Benbrook, Bridgeport, Eagle Mountain, Richland-Chambers, and Cedar Creek. As of 2010, TRWD served a total of 1.7 million consumers as its customer base through over 30 municipalities. TRWD's principal customers are Fort Worth, Arlington, Mansfield, and the Trinity River Authority. Firm in its commitment to deliver high quality water to its customers, TRWD has been proactive in monitoring water quality on these reservoirs.

The Eagle Mountain watershed is located in the eastern portion of the Upper West Fork Trinity Basin including Lake Bridgeport and Eagle Mountain Lake; both impoundments of the West Fork of the Trinity River. Bridgeport flow, sediment and nutrient loads were modeled as a point source into the Eagle Mountain watershed. The remaining 860 square miles to the southeast of Lake Bridgeport drain to Eagle Mountain Lake and are the focus of this investigation.

The impetus for a watershed protection plan comes on the heels of a 20-year water quality analysis project performed by TRWD (Tarrant Regional Water District, 2011). Reservoir managers were charged with producing a long term trend analysis of water quality within the lake and watershed and in doing so were able to establish trend analysis of the Chlorophyll-a, sediment, nitrogen, and phosphorus levels. Watershed conditions including soil erosion, land use, and water pollutant loadings have been assessed for Eagle Mountain using both computer models and ambient water quality testing. An examination of the data from the third quarter main pool sites demonstrated a rising trend of Chlorophyll-a in Eagle Mountain Lake at an annual percentage rate of 3.62 percent. Extrapolation of this rate suggests that chlorophyll-a rate will double in 19 years. Eagle Mountain Lake (Segment 0809) is reported in the 2010 Draft Texas Integrated Report for Clean Water Act Sections 305(b) and 303(d) as having elevated Chlorophyll-a levels in various sections of the lake.

Methods

This investigation of the Eagle Mountain watershed examines the impact of various BMPs on total phosphorous (TP), nitrogen (TN) and sediment inflow into Eagle Mountain Lake. The modeling of BMP effectiveness plays an important role in developing a watershed protection plan. The spatially distributed impacts of BMPs can be helpful for decision makers and stakeholders to identify specific remediation target areas and to identify the most suitable solution(s). The mitigation of water quality problems through the implementation of multiple BMPs in a watershed is a classic scenario in the protection of reservoirs. The ability to evaluate the merit of individual as well as a suite of BMPs and determine the cost-effectiveness of these options permits the evaluation of management plans with lower costs and increased flexibility prior to implementation.

Utilization of several modeling techniques has enabled the project team to integrate attributes of the Eagle Mountain Lake watershed and the Eagle Mountain Lake's performance dynamics in handling nutrient and sediment inflows. The Soil and Water Assessment Tool (SWAT) is a watershed and landscape simulation model designed to help decision makers evaluate soil and water resources at the watershed and river basin scales. The SWAT system is a multi-functional modeling tool that can be used to analyze potential management activities within watersheds and evaluate the impact that those practices have on selected environmental factors. The model operates on a continuous, daily-time step, which makes it capable of simulating changes over many years. Simulation of the watershed encompasses all aspects of the hydrologic cycle including land, water, and atmospheric interactions. SWAT mimics the flow of water within the watershed, allowing it to assess water quality and quantity changes due to alterations in global climate, land use, policy, and technology. SWAT was run for a 35 year period on the Eagle Mountain Lake watershed from 1969 to 2004 to estimate annual loadings of TP, TN and sediment to Eagle Mountain Lake.

Daily mass loadings and inflows from the SWAT model were supplied to the Water Quality Analysis Simulation Program (WASP) model to simulate the lake water quality for a 10 year period from 1994 through 2003. WASP provides water quality planners a dynamic tool to assess management strategies such as nutrient reduction. WASP is a finite-difference model used to interpret or predict possible changes in the water quality of ponds, lakes, reservoirs, rivers and coastal waters brought about by pollutants. Use of the WASP modeling techniques allowed project consultants to determine the impact of sediment and nutrients within a horizontally- and vertically-segmented model of Eagle Mountain Lake. WASP was used in the Eagle Mountain planning efforts to systematically determine the necessary phosphorus load reductions that resulted in statistically significant reductions in Chlorophyll-a at a main lake site.

Although the full scope of the project encompasses attention to TP, TN and sediment annual inflows, the primary objective for the economics analysis of the Eagle Mountain Lake watershed was to identify the most economic, cost-efficient means of reducing the current inflows of TP by 30 percent. A first step toward realizing this objective is to review and define all BMPs that have the potential to be technically and economically feasible. Technical feasibility means that the management practice results in measurable reductions in TP inflows. Economic feasibility suggests that the management practice is both likely to be adopted, implemented and maintained and done so in a manner that is financially acceptable. The consideration of potential BMPs began with a list compiled for the Cedar Creek watershed and was modified to remove BMPs that were unsuitable for the Eagle Mountain watershed while adding new BMPs that were deemed to be more appropriate (Rister et al., 2009).

The end result of this organized "sifting process" was an array of BMPs that were initially identified for TRWD's consideration. For each of these BMPs, an array of economic and financial information had to be compiled and integrated in order to assess the relative environmental and economic merits of the alternative practices over the term of the 50-year project period. The information related to each BMP specifically included:

- level of current implementation and magnitude of additional adoption possible;
- the reduction impacts on TP, TN, and sediment inflow expressed in the same units, i.e., as a total percent of the initial inflow levels;

- expected life (i.e., years of productive reduction in TP, TN, and sediment) for the BMP;
- construction period, i.e., what length of time is required to construct and implement the BMP;
- initial investment and practice establishment costs (including incentives) required;
- recurring annual costs required, i.e., operating and maintenance costs;
- intermediate capital replacement costs to insure each BMP reaches its expected useful life; and
- appropriate inflation rate by which to increase future costs.

A total of 24 BMPs were identified as potentially suitable for the Eagle Mountain Lake watershed. In general terms, the BMPs were defined in categories pertaining to cropland, pasture and rangeland, channel, urban, in-lake, and watershed. Cropland, pasture and rangeland, and channel BMPs were specified to comply with the most recent design parameters prescribed by USDA-NRCS guidelines (USDA National Resources Conservation Service 2010). Urban and in-lake BMPs were specified according to detailed trial results compiled by TRWD personnel (Andrews 2011; Ernst 2011). Finally, watershed BMPs were specified in a detailed report outlining necessary wastewater treatment plant upgrade investments needed to accommodate water demands through 2050 within the watershed study area (Alan Plummer Associates, Inc. 2008).

Eligible Area for BMP Implementation

SWAT analyses were conducted for each individual BMP in those sub-watershed areas in which the respective BMPs were considered feasible. Potential areas of implementation within the total watershed were identified in these analyses. Some BMPs entailed the implementation of the practice on a "project basis." Specifically, the urban, channel-wetland, in-lake, and watershed BMPs are comprehensive projects that must be "implemented in their entirety" or "not implemented at all." In these cases, the BMPs were considered in relation to the magnitude/scale of the project necessary to produce the intended environmental results. Table 1 identifies the comprehensive list of the BMPs, their BMP category, and the eligible area for the practice within the Eagle Mountain Lake watershed.

Phosphorous Removal Efficiency

In addition to the estimate of eligible area for each BMP implementation, the SWAT model also provided an initial estimate of the potential overall reduction in TP, TN, and sediment associated with each BMP. For selected BMPs (those affiliated with the In-Lake category), WASP modeling was used to identify their respective effectiveness levels. For the composite urban category BMPs, TRWD management extrapolated effectiveness levels from journal-published research. For the wetland BMPs in the channel category, SWAT analyses were modified by TRWD management to reflect expected operation procedures. Based on this procedure, it was estimated that the annual average levels of nutrient/sediment inflow into Eagle Mountain Lake were 173,020 kilograms P, 1,055,220 kilograms N and 296,400 tons of sediment. These benchmark inflow levels serve as the baseline for which reduction in nutrient and sediment inflows were measured.

Table 2 provides the initial estimated standards of nutrient and sediment inflow into Eagle Mountain Lake. It then provides a list of the 24 BMPs under consideration and their annual reduction capabilities for TP, TN, and sediment. In terms of TP reduction, the most effective practices were conversion of cropland to grass/hay (15.20%), establishment of filter strips (12.70%), and voluntary urban nutrient management (8.69%). Among the least effective

TP reduction practices were: establishment of riparian buffer strips in medium erosion areas, wetland development in the Walnut Creek area, hypolimnetic aeration, and the wastewater treatment plant BMPs; all with less than one percent annual TP reduction capabilities.

Current, Most Likely, and Maximum Adoption Rates

The potential reduction in P inflow levels for each BMP is greatly influenced by the current level of implementation attached to each BMP along with the additional area that could be expected to adopt each practice. If a BMP was identified to be highly implemented already, the prospects for additional implementation (and further TP reduction) are greatly limited. However, if a BMP is currently implemented at a low adoption rate, but has the potential to be adopted on a wider scale, then it provides greater TP reduction possibilities.

Lee et al. (2010) showed that the TP reduction capabilities for each BMP could be calculated as:

where: FA is the 100 percent adoption rate, MA is the marginal adoption rate, and CA is the current adoption rate. The approach embodied in this equation recognizes that some BMPs have already been adopted for a portion (CA) of the area for which further adoption is being considered. These relationships are presented graphically in figure 1.

An Assumption is that the 100 percent adoption rate is associated only with the remaining portion (1-CA) of the total possible area in the watershed. This is because the model calibration included the existing BMPs, as mentioned earlier. Discussions with project collaborators, stakeholders, and decision-makers responsible for adopting and implementing the BMPs identified in the most-likely marginal adoption (MA) rate, representing that portion of the total area in which a BMP is likely to be implemented, considering property owners' goals and objectives, economic incentives, and other relevant conditions. The relationship described above facilitates translation of the MA proportion of the total remaining area to be treated with the BMP (1 - CA) after eliminating the area already treated (CA) and adjusts the SWAT estimate of TP reduction proportionally.

In April 2011, a meeting was held with Eagle Mountain watershed landowners, stakeholders and local/regional NRCS personnel to discuss the alternative BMPs and identify the current level of adoption for the set of 24 BMPs. Additionally, participants were asked to identify the most likely adoption rates for each practice as well as the feasible adoption rate that could be expected should sufficient cost-share programs and/or incentives be provided. Project team members and several agricultural stakeholders participated in this Delphi technique interview process. Also identified during these discussions were levels of monetary incentive payments that would be required to induce landowners to participate in implementing the various agricultural BMPs. The Delphi process involved the repeated interviewing of the several noted experts until a consensus was reached, representing what is perceived as the most accurate information possible under the existing funding and time constraints. Table 3 presents the best estimates of the current, feasible and most likely adoption rates for each BMP in the Eagle Mountain Lake watershed as defined by the expert panel.

For each BMP, the current adoption rate indicates the expert panel's assessment of existing adoption for the BMP practice within the Eagle Mountain Lake watershed. The most likely adoption rate represents an adoption rate that participants identified as a realistic adoption rate that could be expected with a combined effort of promotion, education and assuming adequate funding is available to construct and maintain the respective BMPs through a 50-year planning horizon. The feasible adoption rate represents the maximum expected adoption rate for each BMP that could be expected. This scenario recognizes the impossibility of convincing all eligible resource managers to participate in a selected practice, even with the presence of financial incentives. For the sake of this analysis, the marginal adoption rate was used and considers the additional implementation of each BMP between the current and most likely adoption rates. The marginal adoption rate reflects the additional implementation (to the current level) for each BMP in the watershed that could be expected if an adequate level of incentives were provided as part of a watershed protection program.

Following the elicitation of the above-noted probable adoption rates for each BMP and the potential spatial areas affected, the original SWAT and WASP estimates of the effectiveness levels for the BMPs in terms of their impacts in reducing TP, TN, and sediment inflows into Eagle Mountain Lake were adjusted. An example of calculating the impact of the marginal adoption of an individual BMP can be seen by examining the information for BMP 5 (Terracing). As shown in tables 2 and 3, the current level of adoption for this practice is 20 percent of the acreage considered suitable for terracing. If terraces were to be implemented on all of the remaining 80 percent of such acreage, then TP would be reduced by 6.8 percent of the targeted inflow. Since the most likely adoption rate for this practice is 30 percent and the current adoption rate is 20 percent, only 10 percent of the available acreage would be available for further adoption (i.e. the marginal adoption rate is 10 percent). Therefore, the projected reduction in TP from BMP 5 (Terracing) is 10% divided by (1 - 20%) times the 6.8% total or 0.125 X 6.8% = 0.85%.

Costs for Best Management Practice Implementation

The cost information for each BMP was assessed through consultations with agency professionals and was thoroughly discussed and reviewed among project team members. The sequence and timing of establishment, operation and maintenance costs as well as the expected duration for each BMP was constructed to reflect a 50-year project period. For each BMP considered, additional specifications were declared, allowing the calculation of units (e.g., acres, structures, etc.) that could be imposed on the potentially eligible spatial areas. This was necessary to aggregate the cost of implementing each BMP across the area represented by the marginal adoption rate.

The assorted nuances of each individual BMP required the construction of individual economic budgets for each practice, independent of others that might also be implemented. For each BMP, attention was focused on identifying all relevant costs, regardless of the entity/individual incurring the costs. This included any possible inducement payments required to encourage or secure the participation of resource managers in the Eagle Mountain Lake watershed.

In June 2011, project team members met by teleconference with several members of the local/regional USDA-Natural Resources Conservation Service (NRCS) field staff who administer similar and identical programs for crop and pasture/range lands within the region. Each cost figure and investment timeline assumption was reviewed and adjusted (item by item) (Leal, 2011). Additional details associated with urban, channel, reservoir, and flood protection sites were obtained through a review of cost/investment details associated with the Cedar Creek project. In consultation with TRWD personnel, this data was modified to conform to the specific attributes of the Eagle Mountain Lake watershed. This resulted in a set of cost estimates and investment timing considerations that were determined to be an accurate representation of the costs and investment timing needed to implement each BMP over the 50 year project period.

Costs to implement each BMP were identified (in 2011 dollars) for a 50-year planning horizon assuming adoption at the most likely adoption rate. An annual inflation rate of 2.043 percent and a discount rate of 4.20 percent (Office of Management and Budget, 2010) were used to facilitate calculations of net present values of costs and annuity equivalent values. The cost estimates reflected documented costs (if available) or the consensus estimates of the Eagle Mountain Lake watershed project team members. In anticipation of some time lag in the implementation of these BMPs, and in recognition of the uncertainty and dynamics of the current economy, an additional 10 percent contingency factor was incorporated when individual BMP costs were estimated.

Results

A Microsoft® Excel® spreadsheet was constructed to calculate the net present value (NPV) of all costs over the expected useful life of each BMP for the 50-year project period. In addition, an annuity equivalent value (AEV) was calculated for each of the BMPs, assuming implementation of the marginal adoption rates within the SWAT- (and WASP-) designated sub-watershed areas of the Eagle Mountain Lake watershed. A social discount rate of 4.20 percent was assumed to facilitate calculations of net present values and annuity equivalent values. The calculated AEVs represent the annual payment necessary in each of the 50 years of the project period to finance the implementation of the BMP practice/project. Transforming NPV into an AEV facilitates accurate relative comparisons of costs across BMPs.

Table 4 provides the estimated NPVs of costs for each BMP implemented at the respective marginal adoption rate. These values are also broken out to show two components of the NPV for each BMP. The NPV of the initial construction and establishment costs correspond to the Year 0 costs in the 50-year project period sequence. This value represents the upfront investment necessary for initial BMP implementation. The NPV of operating and maintenance costs represents the present value of costs for ongoing operating and maintenance plus intermittent capital replacement costs for each BMP that are incurred during Years 1 through 50.

Because these NPV estimates reflect implementation at the marginal adoption rate, a larger potential area for BMP adoption translates into a higher NPV. Larger NPV estimates for BMPs could be the result of either: high project costs, a project large in size or the adoption of the practice across a large area. In terms of overall BMP implementation costs, the lowest estimated NPVs were BMP 15 (Herbicide Application - Riparian corridor) at $46,945, followed by BMP 4 (Establish Grassed Waterways) at $107,529, and BMP 10 (Prescribed Burning) at $187,874. BMP 12 (Phase II Urban Stormwater BMPs) was the most expensive practice ($60.5 million), followed by BMP 24 (Flood Protection Sites) at $32.4 million, BMP 18 (Wetland Development - West Fork Trinity) at $29.6 million, and BMP 23 (WWTP - Level I to Level III) at $24.9 million.

Table 5 provides the conversion of the NPVs for each BMP into an estimated AEV of costs for each BMP implemented at the marginal adoption rate. The AEVs are also broken out to show the portion of the annual payments attributable to the upfront establishment costs and ongoing operating and maintenance costs for each BMP. The AEV of the initial construction and establishment costs correspond to the annual payments (for 50 years) necessary to pay for the initial practice/project establishment. The AEV of operating and maintenance costs represents the annual payments (for 50 years) necessary to pay for the ongoing operation and maintenance costs associated with each BMP throughout the 50-year project period. Because the SWAT, WASP and other environmental modeling characterize the annual nutrient and sediment inflows (and reduction capabilities), the AEV serves to provide a common measure in terms of annual costs. This common time component lends itself for appropriate utilization in pairing the environmental benefits of the respective BMPs with their estimated costs and serves as the basis for the derivation of relative cost-efficiency rankings of the BMPs.

Efficiency Rankings of Best Management Practices

Three components of research are required to identify useful economic information for TRWD's management to use in identifying and implementing the most-efficient strategies for reducing undesirable nutrient inflows into the Eagle Mountain Lake. Essential for the success of these components is extensive consideration of the characteristics of the Eagle Mountain Lake watershed nutrient and sediment inflow problem and the remediation alternatives identified through SWAT and WASP modeling and previous research by members of the project team. The final component is pairing these environmental metrics with an economic assessment.

Explicit recognition of the initial SWAT effectiveness levels for TP, TN, and sediment for each BMP were incorporated into the spreadsheet, along with the details of the eligible spatial area of the watershed and most likely marginal adoption rate of each BMP. The cost and nutrient and sediment reduction information presented is also transformed to relate the annual cost per unit of TP, TN, and sediment reduction. In calculating these costs per unit of reduction, each item is evaluated independently, assuming all costs are associated with reducing that item (TP, TN, or sediment) and ignoring any allocation of costs toward reducing the others.

Table 6 shows the estimated annual cost of BMPs with respect to reductions in TP, TN, and sediment. The rank ordering of BMPs with respect to the focus of this investigation (TP reduction) will be presented in the next section. However, it is worth noting the BMPs that were deemed most cost-efficient for TN and sediment reduction. For reduction of TN, BMP 3 (Establish Filter Strips): $2.66/kg.; BMP 9 (Grade Stabilization - gully plugs): $3.50/kg.; and

BMP 15 (Herbicide Application - Riparian corridor): $14.28/kg were identified as the most cost-efficient BMPs. For reduction of sediment, BMP 3 (Establish Filter Strips): $3.64/ton; BMP 4 (Establish Grassed Waterways): $4.60/ton; and BMP 9 (Grade Stabilization - gully plugs): $8.10/ton were identified as the most cost-efficient BMPs. If multiple environmental objectives were desired for a watershed protection plan, these BMPs would likely enter into the selection framework for consideration.

Each BMP was assessed by its cost per kilogram of TP reduction, and the BMPs were ranked by their costs to identify their relative cost-efficiency. This ranking integrates the annual cost of BMP implementation with the respective efficiency in addressing TP reduction in the watershed. Table 7 provides these relative rankings. The top four BMPs in terms of cost-efficiency for TP reduction are inclusive of the top three cost-efficient practices identified for TN and sediment reduction. This lends credibility to their merit as useful BMPs regardless of the nuisance issue among these three components. The most striking detail of the information reported in table 7 is the wide range of cost-efficiency that exists across the 24 BMPs considered. For implementation of each BMP at the most likely adoption rate in the Eagle Mountain Lake watershed, reductions of TP inflow could cost as little as $6.39/kg reduced (BMP 3 Establish Filter Strips) or as much as $1,431.70/kg (BMP 16 Riparian Buffer Strips - medium erosion areas). This implies that a properly constructed watershed protection plan focusing on TP reduction would be well advised to concentrate its emphasis on the cost-efficient BMPs identified in this ranking. A lot of money could be wasted on inferior projects. The less cost-efficient BMPs on this list might be beneficial endeavors/projects for other objectives, but do not provide the best return on investment if the primary area of concern is reducing TP inflows.

Identifying the Optimal Suite of Best Management Practices

For the Eagle Mountain Lake watershed, the primary objective is to reduce annual TP inflows into the lake by 30 percent. However, watershed planners wish to monitor the ancillary impact of targeted BMPs on the annual inflows of TN and sediment as well. In determining the optimal solution, this economic analysis considers the technical nutrient/sediment reduction performance of each BMP and the internally-calculated costs per unit of TP, TN, and sediment reductions toward meeting the Eagle Mountain Lake watershed management's objectives.

In order to determine how many BMPs are needed to achieve the 30 percent TP reduction goal, SWAT modeling incorporated sequential adoption of BMPs beginning with full adoption of the most cost-efficient BMP at is marginal adoption rate and then advancing to the next most cost-efficient BMP. The environmental implications of this implementation were successively tabulated to determine if additional BMPs were necessary. BMP implementation was targeted at the sub-basin level which indicated the greatest potential for total P reduction. The process was repeated until the watershed management goal of 30 percent total P reduction was achieved. This methodology will also assist in implementation of practices by determining the sub-watersheds which demonstrate the best response to selected BMPs.

The suite of BMPs estimated to achieve the 30 percent reduction in total P inflow into the Eagle Mountain Lake based on the previously noted data from SWAT, WASP, and other modeling research of the project team are reported in table 8. This list of BMPs is identified as the cost-efficient BMP suite since the selection was based solely on the BMPs which were found to be the most efficient in terms of lowest cost per unit of TP reduction. A total of 14 of the 24 BMPs considered were found to be necessary to reach the 30 percent target. The table reveals the cumulative costs and incremental nutrient and sediment reduction impacts provided by the

BMPs (beginning with the most cost efficient and progressing down the ranked cost-efficient BMP list). For this suite of BMPs, cumulative reductions in TP, TN and sediment inflows totaled 31.3, 14.7 and 20.0 percent, respectively, of current inflow levels.

The estimated NPV (2011 dollars) required to implement the cost-efficient suite of BMPs was found to be $95,183,982. Of this total, a NPV of $38,911,913 is necessary to fund the initial establishment and construction costs of the BMPs (Year 0 investment) and a NPV of $56,272,069 is needed to fund the operating and maintenance costs (Year 1 through 50 investment). While expenses will be incurred initially and throughout the 50-year project period, the $95.2 million NPV estimate represents the upfront funds needed to implement and maintain the suite of BMPs for the entirety of the planning horizon.

The Annuity Equivalent Value (AEV) cost of the cost-efficient suite of BMPs is $4,583,626, representing the annual expenditure necessary each year during the 50-year project period. Of this annual expenditure, a total of $1,873,823 is necessary to fund the initial establishment and construction costs of the BMPs (Year 0 investment) and a total of $2,709,803 is needed to fund the operating and maintenance costs (Year 1 through 50 investment).

Cropland BMPs are the greatest contributors, providing 44.4 percent of the expected reduction. Watershed BMPs are second in importance contributing 13.4 percent of the total, followed by urban BMPs at 12.1 percent, pasture and rangeland BMPs at 11.2 percent, in-lake BMPs at 10.5 percent, and channel BMPs at 8.3 percent. None of the WWTP BMPs were sufficiently cost-efficient to fit into the comprehensive plan.

This presentation of the cumulative costs and environmental impacts highlights the non-linear nature of costs from increased nutrient and sediment reduction targets. Notice that a 20 percent TP reduction target could be achieved by implementing only 7 of the BMPs (at the same level of adoption) with a NPV of program costs of $13.25 million or an AEV of $638,098 for each year in the 50-year project period. In other words, raising the TP inflow reduction target from 20 percent to 30 percent raises the estimated costs of the watershed protection plan by over 600 percent (NPV increased by $81.93 million; AEV increased by $3.95 million).

Additionally, BMP 20 (Hypolimnetic Aeration) and BMP 21 (P Inactivation with Alum) are mutually exclusive (i.e. only one of these could be utilized). While both practices appeared in the list as more cost-effective BMPs than others appearing on this list, BMP 21 (P Inactivation with Alum) was chosen because it was more effective with respect to TP reduction. Even though BMP 21 (P Inactivation with Alum) was the least cost-efficient of these two practices, the enhanced TP reduction effectiveness paired with a better cost-efficiency relative to other BMPs necessary to meet the target dictated selection of BMP 21 (P Inactivation with Alum) over the BMP 20 (Hypolimnetic Aeration) alternative.

Finally, several of the BMPs under consideration were, by nature, projects that must be implemented in their entirety or omitted altogether. This includes several BMPs that fall in cost-efficient rank ordering on the borderline of inclusion necessary to produce the explicit 30 percent TP reduction target. By incorporating BMP 18 (Wetland Development - West Fork Trinity), the estimated cumulative TP reduction level advances from 29.4 percent to 31.3 percent. Implementing this BMP is appropriate in terms of strictly adhering to the sequentially preferred cost-effective rank order of BMPs, however, it results in a suite of BMPs that exceeds the 30 percent target at a significant cost increase for the collective BMP program. Based on this unique situation, an alternative solution is provided in order for decision-makers to fully consider an approach that might be deemed more practical, acceptable and/or appropriate.

Table 9 presents a list of BMPs identified as the cost-effective suite which is estimated to achieve a 29.9 percent reduction in TP inflow into the Eagle Mountain Lake. Rather than adopt BMP 18 (Wetland Development - West Fork Trinity) solely because it is the next in line based on the ranked order of TP reduction cost-efficiency, the more relevant investigation would be identifying which BMP can provide the remaining TP reduction necessary at the lowest overall cost. BMP 18 (Wetland Development - West Fork Trinity) is a large scale project with the potential to contribute to the TP reduction effort. However, it also adds a NPV of $29.65 million to the overall watershed management plan costs or an annual cost (AEV) of $1.43 million. Alternatively, while less cost-efficient at the margin by comparison, BMP 13 (Voluntary Urban Nutrient Management) only adds a NPV of $6.08 million to the overall watershed management plan costs or an annual cost (AEV) of $292,574. It is noted that the 29.9 percent reduction in TP inflow does not fully satisfy the explicit 30.0 percent objective. Therefore, decision-makers can decide whether the 25 percent reduction in overall program costs justify this sacrifice or whether sufficient uncertainty exists (regarding the exact precision of estimates) to support selection of the cheaper alternative.

The suite of BMPs presented in table 9 follows the previous format and reveals the cumulative costs and incremental nutrient and sediment reduction impacts provided by the BMPs. This information is identical to that of table 8 until the final entry where the substitution of BMP 13 (Voluntary Urban Nutrient Management) for BMP 18 (Wetland Development - West Fork Trinity) is considered. For this suite of BMPs, reductions in TP, TN and sediment inflows total 29.9, 11.5 and 15.3 percent, respectively, of current inflow levels.

The estimated NPV (2011 dollars) required to implement this suite of BMPs was found to be $71,611,742. Of this total, a NPV of $20,492,963 is necessary to fund the initial establishment and construction costs of the BMPs (Year 0 investment) and a NPV of $51,118,779 is needed to fund the operating and maintenance costs (Year 1 through 50 investment). While expenses will be incurred initially and throughout the 50-year project period, the $71.6 million NPV estimate represents the upfront funds needed to implement and maintain the cost-effective suite of BMPs for the entirety of the planning horizon.

The Annuity Equivalent Value (AEV) of the cost-effective suite of BMPs is $3,448,495, representing the annual expenditure necessary each year during the 50-year project period. Of this annual expenditure, a total of $986,850 is necessary to fund the initial establishment and construction costs of the BMPs (Year 0 investment) and a total of $2,461,645 is needed to fund the operating and maintenance costs (Year 1 through 50 investment).

In this scenario, cropland BMPs remain the greatest contributors, providing 46.5 percent of the expected reduction. Urban BMPs are second in importance contributing 14.4 percent of the total, followed by watershed BMPs at 14.1 percent, pasture and rangeland BMPs at 11.7 percent, in-lake BMPs at 11.0 percent, and channel BMPs at 2.3 percent. The same message is conveyed in this illustration; that participation from all BMP categories is needed to achieve the watershed management plan objectives. The importance of securing the participation from agriculture is again important as cropland and pasture and rangeland BMPs account for 58.2 percent of the contributed TP reduction within this watershed protection plan.

Discussion

This economic analysis of BMPs has revealed a number of important issues that underpin a successful watershed protection plan. Aside from identifying the most cost-efficient and cost-effective combination to achieve the 30 percent TP reduction goal, it highlights the need for broad participation from stakeholders, the funding levels needed to accomplish the plan, the importance of individual BMPs to keep costs reasonable, and the need for a coordinating entity to oversee the plan. Each of these issues is given more reflection below.

Reliance on Participation from Multiple Entities

Projects of the magnitude of the Eagle Mountain Lake watershed protection plan are dependent upon the participation of a wide array of stakeholders and affected entities. Regardless of the strategy chosen to meet the TP reduction goal, participation from several interest groups is an absolute necessity. Obviously, funding availability, decision-makers' planning horizons, future land use and development intentions, the general economic environment, and municipal, county, state, and federal policy are all dynamic factors influencing which BMPs will prove to be most viable. Active involvement, educational outreach and solicitation of guidance from all stakeholders will increase the stakeholder buy-in necessary for the watershed protection plan to be successful.

Funding for BMP Implementation

Successful acquisition of funding to support initial and continuing implementation of management measures is critical for the success of the Eagle Mountain watershed protection plan. While some management measures require only minor adjustments to current activities, some of the most important measures require significant funding for both initial and sustained implementation. All of the BMPs require a long-term commitment; both in terms of financial investment as well as resolute determination from resource owners/managers to assure the BMPs accomplish their potential. Sufficient funding for a project of this magnitude will likely involve multiple approaches to funding, strong partnership alliances to leverage technical, financial, and personnel resources, coordination of those resources, and a plan for the systematic implementation of practices that can be implemented as funding becomes available. This economic analysis identified viable and cost-efficient BMPs that impact multiple stakeholder groups. The available funding sources available to all of these groups will need to be fully exploited in order to secure the financial commitments necessary for this watershed protection plan to achieve the intended objectives.

Significant Variation in the Relative Cost-Efficiency of BMPs

The optimal economic solution will be based on a myriad of factors. When the costs of the respective BMPs are ranked according to cost-efficiency (i.e. cost per unit of TP reduction), the range of cost-efficiency is extensive. This disparity clearly identifies those practices that should be the emphasis of any efforts to reduce TP inflow into the Eagle Mountain Lake, even if funds are not available to finance the entire watershed protection plan. Although the environmental impact associated with reducing TN and sediment was identified, the focus of this analysis was exclusively on TP reduction. If multiple environmental objectives were simultaneously desired, the resulting suite of BMPs identified as optimal for a watershed protection plan would likely be different if the plan required more than four or five BMPs to accomplish.

Impact of Adoption Rates

The optimal suite of BMPs identified in this analysis is greatly influenced by the consensus identification of current and most likely adoption rates for each BMPs. These measures for each BMP, define the marginal adoption rate (i.e. additional eligible area that is likely to adopt a specific BMP). Significant time and effort can be spent investigating which of the borderline BMPs should be included to fully reach the intended target TP reduction levels. However, a review of the cost-efficiency rankings of BMPs in conjunction with the adoption rates suggests that this time would be better spent identifying how a greater level of adoption could be attained for those BMPs that demonstrated the most cost-efficiency. If a higher adoption rate for the most cost-efficient BMPs can be achieved, the potential exists for the costs of the watershed protection plan to be greatly reduced. Higher adoption of more efficient BMPs would replace the need to include higher cost, less efficient BMPs from inclusion the watershed protection plan. While several BMPs included an estimate of an incentive payment to secure participation, thoughtful consideration should be given to the additional participation that could be secured if incentive payments were higher than those assumed in this analysis. There are limits to the amount of financial incentive that can be provided to secure additional adoption of specific BMPs while maintaining cost-efficiency relative to other alternatives. However, those limits should be identified and the differential value built into a plan that would encourage maximum participation for the most cost-efficient BMPs.

Coordination of Watershed Protection Management Plans

Implementation of a model-generated solution on such a large-scale project involving numerous stakeholders with no one central authority is a complex paradigm. Assuming the funding issues discussed previously can be successfully managed, several issues remain to be considered and managed. Targeted implementation of specific BMPs assumes that a coordinating body has the ability to offer participation benefits to certain resource managers without having to accommodate others who might fall outside of the targeted sub-basin area. Alternatively, participation by resource owners lying outside of the targeted sub-basins raises the cost of the program disproportionately to the benefits that are actually obtained. Identifying methods that secure participation of critical BMPs in targeted sub-basins while minimizing participation of non-critical BMPs in non-targeted sub-basins is a challenge that will require thoughtful project design. In addition, the watershed protection plan must also facilitate, encourage and support maximum participation by resource managers to encourage the implementation of the more cost-efficient BMPs beyond the adoption rates assumed in this analysis. Therefore, a viable coordinating entity must be engaged with all stakeholder groups, be proactive and have the ability to monitor the implementation of the specific BMPs that are chosen as part of the overall watershed protection plan.

Conclusion

The purpose of this economic analysis was to evaluate individual BMPs with a primary objective of identifying a combination that could achieve a 30 percent reduction of TP inflows into the Eagle Mountain Lake. This suite of BMPs could be implemented and maintained over the span of a 50-year project period as part of an economically viable Eagle Mountain Lake watershed protection plan. Considering and accepting all of the assumptions developed in the course of the SWAT, WASP, and economic analysis embedded in this analysis, it was determined that the 30 percent target TP reduction level is achievable.

This economic analysis for the Eagle Mountain Lake watershed project extends beyond the SWAT and WASP modeling efforts to evaluate a total of 24 BMPs for potential inclusion in a watershed protection plan. The eligible area for each of these BMPs was identified, their potential to reduce TP, TN and sediment inflows into the lake was identified, current and most-likely adoption rates for each BMP was estimated, and the cost for implementation was calculated to help determine a relative ranking of cost-efficiency. All of this information was synthesized to estimate the expected potential costs associated with adopting and implementing alternative suites of BMPs to collectively meet the 30 percent TP inflow reduction target. Two separate strategies, a cost-efficient suite of BMPs and a cost-effective suite of BMPs, each containing 14 BMPs were highlighted as possible solutions.

The cost-efficient suite of BMPs was estimated to reduce TP, TN and sediment inflow levels by 31.3, 14.7, and 20.0 percent, respectively. For this strategy, the financial cost for achieving a 31.3 percent reduction was identified to be $4,583,626 annually for each of the 50-years in the project period. Up front, (time 0) initial construction costs were estimated to be $38,911,913. While this collection of BMPs is the most cost-efficient (from a $/kg of TP reduced perspective), it exceeds the target TP reduction level at a significant cost because the final BMP included is a large scale project. For this reason, an alternative solution was presented that substituted a smaller scale project as the final BMP for the plan. The cost-effective suite of BMPs was estimated to reduce TP, TN and sediment inflow levels by 29.9, 11.5, and 15.3 percent, respectively. For this strategy, the financial cost for achieving a 29.9 percent reduction was determined to be $3,448,495 annually for each of the 50-years in the project period. Up front, (time 0) initial construction costs were estimated to be $20,492,963. Central to both of these strategies was the participation from several stakeholder groups, specifically agricultural cropland and pasture and range resource managers.

References

Alan Plummer Associates, Inc. 2008. Tarrant Regional Water District Watershed Project: Eagle Mountain Wastewater Treatment Facilities Report. Austin, TX.

Andrews, D. 2011. Environmental Division, Tarrant Regional Water District, Fort Worth, TX. Personal communications.

Ernst, M.R. 2011. Environmental Manager, Tarrant Regional Water District, Fort Worth, TX. Personal communications.

Gee, K. and J. Biermacher. 2007. Prescribed Burning - What is the Cost? The Samuel Roberts Noble Foundation Research Report. Ardmore, OK. http://www.noble.org/Ag/Research/Articles/PrescribedBurning/index.html Accessed June 2011.

Leal, Alfonso. 2011. Assistant State Conservationist, USDA - Natural Resources Conservation Service, Weatherford, TX. Personal communications.

Lee, T., M. E. Rister, B. Narashimhan, R. Srinivasan, D. Andrews, and M. R. Ernst. Evaluation and Spatially Distributed Analyses of Proposed Cost-Effective BMPs for Reducing Phosphorous Level in Cedar Creek Reservoir, Texas. Transactions of the American Society of Agricultural and Biological Engineers, Vol. 53(2): 1619-1627.

Office of Management and Budget. 2010. "Table of Past Years Discount Rates, Appendix C." Guidelines and Discount Rates for Benefit-cost Analysis of Federal Programs. OMB Circular No. A-94. December.

Rister, E. M., R. D. Lacewell, A. W. Sturdivant, T. Lee, R. Srinivasan, B. Narashimhan, C. Wolfe, D. Waidler, D. Andrews, M. Ernst, J. Owns, B. Lessikar, L. F. Gregory, A. Jones, B. L. Harris, E. K. Seawright, and S. R. Yow. 2009. NCTXWQ project: Evaluating the Economics of Best Management Practices for Tarrant Regional Water District's Cedar Creek Reservoir Watershed. College Station, Texas: Texas Water Resources Institute. Report TR-357.

Tarrant Regional Water District. 2011. Tarrant Regional Water District Water Quality Trend Analysis 1989-2009 Final Report. http://www.trwd.com/Libraries/Water_Quality/Combined_Exec_and_Tech_Reports.sflb.ashx. Accessed August 2011.

USDA Natural Resources Conservation Service. 2010. National Conservation Practice Standards - NHCP. http://www.nrcs.usda.gov/technical/standards/nhcp.html Accessed July 2011.

Table 1. Best Management Practices (BMPs), Description, Category and Eligible Area in the Eagle Mountain Lake Watershed.

BMP	Description	Category	Eligible Area Total	Eligible Area Unit
1	Conversion of Cropland to Grass/Hay	Cropland	17,509.0	acres
2	Fert. Mgt. - 25% reduced P application	Cropland	17,509.0	acres
3	Establish Filter Strips	Cropland	17,509.0	acres
4	Establish Grassed Waterways	Cropland	3,503.0	acres
5	Terracing	Cropland	8,646.0	acres
6	Prescribed Grazing	Pasture & Range	50,162.0	acres
7	Pasture Planting - reseeding	Pasture & Range	50,162.0	acres
8	Critical Pasture Planting - shaping	Pasture & Range	190,580.0	acres
9	Grade Stabilization - gully plugs	Pasture & Range	203,703.0	acres
10	Prescribed Burning	Pasture & Range	64,247.0	acres
11	Brush Management	Pasture & Range	32,123.5	acres
12	Phase II Urban Stormwater BMPs	Urban	1.0	project
13	Voluntary Urban Nutrient Mgt.	Urban	1.0	project
14	Required Urban Nutrient Mgt.	Urban	1.0	project
15	Herbicide Application - Riparian corridor	Channel	49.5	miles
16	Riparian Buffer Strips - Med Erosion Areas	Channel	288.3	miles
17	Riparian Buffer Strips - Critical Areas	Channel	52.2	miles
18	Wetland Development - West Fork Trinity	Channel	1.0	project
19	Wetland Development - Walnut Creek	Channel	1.0	project
20	Hypolimnetic Aeration	In-Lake	1.0	project
21	P Inactivation with Alum	In-Lake	1.0	project
22	WWTP - Level I to Level II	Watershed	ALL	projects
23	WWTP - Level I to Level III	Watershed	ALL	projects
24	Flood Protection Sites - Big Sandy/Salt Creek	Watershed	17	sites

Table 2. Best Management Practices (BMPs) and Initial Estimated Standards of Reduction (in percent) of Total Phosphorous (P), Nitrogen (N) and Sediment Levels.

		Initial Estimated Standards		
		Total P 173,020 kg.	Total N 1,055,220 kg.	Sediment 296,400 tons
		Reduction In:		
BMP	Description	Total P	Total N	Sediment
1	Conversion of Cropland to Grass/Hay	15.20%	7.30%	14.20%
2	Fert. Mgt. - 25% reduced P application	1.20%	-0.20%	0.00%
3	Establish Filter Strips	12.70%	5.00%	13.00%
4	Establish Grassed Waterways	3.10%	0.20%	3.80%
5	Terracing	6.80%	2.50%	7.10%
6	Prescribed Grazing	1.70%	0.30%	0.50%
7	Pasture Planting - reseeding	1.70%	0.30%	0.50%
8	Critical Pasture Planting - shaping	1.50%	4.60%	1.80%
9	Grade Stabilization - gully plugs	4.00%	2.80%	4.30%
10	Prescribed Burning	1.80%	0.50%	1.10%
11	Brush Management	1.70%	0.30%	1.10%
12	Phase II Urban Stormwater BMPs	8.00%	0.00%	4.00%
13	Voluntary Urban Nutrient Mgt.	8.69%	6.61%	0.00%
14	Required Urban Nutrient Mgt.	5.10%	0.70%	-4.60%
15	Herbicide Application - Riparian corridor	1.70%	0.30%	1.10%
16	Riparian Buffer Strips - Med Erosion Areas	0.40%	0.30%	4.10%
17	Riparian Buffer Strips - Critical Areas	1.60%	1.30%	14.30%
18	Wetland Development - West Fork Trinity	2.76%	4.17%	5.50%
19	Wetland Development - Walnut Creek	0.44%	0.41%	0.70%
20	Hypolimnetic Aeration	0.53%	0.00%	0.00%
21	P Inactivation with Alum	3.25%	0.00%	0.00%
22	WWTP - Level I to Level II	0.30%	-0.20%	0.00%
23	WWTP - Level I to Level III	0.60%	0.30%	0.00%
24	Flood Protection Sites - Big Sandy/Salt Creek	4.40%	5.20%	5.00%

Table 3. Best Management Practices (BMPs) and Estimated Adoption Rates within the Eagle Mountain Lake Watershed.

BMP	Description	Adoption Rates of BMPs			
		Current	Feasible	Most Likely	Marginal
1	Conversion of Cropland to Grass/Hay	0%	50%	25%	25%
2	Fert. Mgt. - 25% reduced P application	90%	100%	100%	10%
3	Establish Filter Strips	0%	50%	25%	25%
4	Establish Grassed Waterways	20%	60%	30%	10%
5	Terracing	20%	60%	30%	10%
6	Prescribed Grazing	10%	50%	30%	20%
7	Pasture Planting - reseeding	5%	20%	10%	5%
8	Critical Pasture Planting - shaping	30%	75%	40%	10%
9	Grade Stabilization - gully plugs	25%	75%	50%	25%
10	Prescribed Burning	1%	15%	5%	4%
11	Brush Management	10%	60%	30%	20%
12	Phase II Urban Stormwater BMPs	0%	100%	50%	50%
13	Voluntary Urban Nutrient Mgt.	10%	25%	15%	5%
14	Required Urban Nutrient Mgt.	10%	80%	70%	60%
15	Herbicide Application - Riparian corridor	0%	10%	5%	5%
16	Riparian Buffer Strips - Med Erosion Areas	5%	50%	10%	5%
17	Riparian Buffer Strips - Critical Areas	0%	10%	10%	10%
18	Wetland Development - West Fork Trinity	0%	100%	100%	100%
19	Wetland Development - Walnut Creek	0%	100%	100%	100%
20	Hypolimnetic Aeration	0%	100%	100%	100%
21	P Inactivation with Alum	0%	100%	100%	100%
22	WWTP - Level I to Level II	0%	100%	100%	100%
23	WWTP - Level I to Level III	0%	100%	100%	100%
24	Flood Protection Sites - Big Sandy/Salt Creek	0%	100%	100%	100%

Table 4. Estimated Net Present Values of Costs for Best Management Practice Implementation with respect to Eligible Area within the Eagle Mountain Lake Watershed.

BMP	Description	Net Present Value of Costs: Initial Construction and Establishment	Operating and Maintenance	Total
1	Conversion of Cropland to Grass/Hay	$ 798,323	$ 6,753,608	$ 7,551,931
2	Fert. Mgt. - 25% reduced P application	$ 16,500	$ 1,886,831	$ 1,903,331
3	Establish Filter Strips	$ 45,619	$ 682,923	$ 728,542
4	Establish Grassed Waterways	$ 26,152	$ 81,377	$ 107,529
5	Terracing	$ 328,991	$ 975,376	$ 1,304,367
6	Prescribed Grazing	$ 406,058	$ 2,228,347	$ 2,634,405
7	Pasture Planting - reseeding	$ 33,053	$ 606,289	$ 639,342
8	Critical Pasture Planting - shaping	$ 527,812	$ 4,890,527	$ 5,418,340
9	Grade Stabilization - gully plugs	$ 336,654	$ 199,559	$ 536,213
10	Prescribed Burning	$ 54,672	$ 133,202	$ 187,874
11	Brush Management	$ 1,015,906	$ 2,475,168	$ 3,491,074
12	Phase II Urban Stormwater BMPs	$ 0	$60,553,355	$60,553,355
13	Voluntary Urban Nutrient Mgt.	$ 0	$ 6,075,608	$ 6,075,608
14	Required Urban Nutrient Mgt.	$ 275,000	$ 2,700,270	$ 2,975,270
15	Herbicide Application - Riparian corridor	$ 7,187	$ 39,758	$ 46,945
16	Riparian Buffer Strips - Med Erosion Areas	$ 396,413	$ 632,392	$ 1,028,804
17	Riparian Buffer Strips - Critical Areas	$ 5,742,000	$ 0	$ 5,742,000
18	Wetland Development - West Fork Trinity	$18,418,950	$11,228,898	$29,647,848
19	Wetland Development - Walnut Creek	$ 4,598,000	$ 3,910,867	$ 8,508,867
20	Hypolimnetic Aeration	$ 165,000	$ 1,023,892	$ 1,188,892
21	P Inactivation with Alum	$ 3,769,218	$ 9,183,383	$12,952,601
22	WWTP - Level I to Level II	$ 1,132,681	$ 3,358,762	$ 4,491,444
23	WWTP - Level I to Level III	$11,680,418	$13,178,438	$24,858,856
24	Flood Protection Sites - Big Sandy/Salt Creek	$13,396,130	$18,983,911	$32,380,041

Table 5. Annuity Equivalent Value of Estimated Costs of Best Management Practice Implementation with respect to Eligible Area within the Eagle Mountain Lake Watershed.

		Annuity Equivalent Value of Costs		
BMP	Description	Initial Construction and Establishment	Operating and Maintenance	Total
1	Conversion of Cropland to Grass/Hay	$ 38,444	$ 325,223	$ 363,667
2	Fert. Mgt. - 25% reduced P application	$ 795	$ 90,861	$ 91,656
3	Establish Filter Strips	$ 2,197	$ 32,886	$ 35,083
4	Establish Grassed Waterways	$ 1,260	$ 3,918	$ 5,178
5	Terracing	$ 15,843	$ 46,969	$ 62,812
6	Prescribed Grazing	$ 19,554	$ 107,307	$ 126,861
7	Pasture Planting - reseeding	$ 1,592	$ 29,196	$ 30,788
8	Critical Pasture Planting - shaping	$ 25,417	$ 235,506	$ 260,923
9	Grade Stabilization - gully plugs	$ 16,212	$ 9,610	$ 25,822
10	Prescribed Burning	$ 2,633	$ 6,414	$ 9,047
11	Brush Management	$ 48,921	$ 119,193	$ 168,114
12	Phase II Urban Stormwater BMPs	$ 0	$2,915,974	$2,915,974
13	Voluntary Urban Nutrient Mgt.	$ 0	$ 292,574	$ 292,574
14	Required Urban Nutrient Mgt.	$ 13,243	$ 130,032	$ 143,275
15	Herbicide Application - Riparian corridor	$ 346	$ 1,915	$ 2,261
16	Riparian Buffer Strips - Med Erosion Areas	$ 19,089	$ 30,453	$ 49,543
17	Riparian Buffer Strips - Critical Areas	$ 276,509	$ 0	$ 276,509
18	Wetland Development - West Fork Trinity	$ 886,973	$ 540,732	$1,427,705
19	Wetland Development - Walnut Creek	$ 221,419	$ 188,330	$ 409,748
20	Hypolimnetic Aeration	$ 7,946	$ 49,306	$ 57,252
21	P Inactivation with Alum	$ 181,508	$ 442,230	$ 623,738
22	WWTP - Level I to Level II	$ 54,545	$ 161,743	$ 216,287
23	WWTP - Level I to Level III	$ 562,476	$ 634,614	$1,197,089
24	Flood Protection Sites - Big Sandy/Salt Creek	$ 645,097	$ 914,178	$1,559,275

Table 6. Estimated Annual Cost of Best Management Practice Implementation with respect to Reductions in Total Phosphorous (P), Nitrogen (N), and Sediment.

		Annual Cost for Reduction in:		
		Total P	Total N	Sediment
BMP	Description	per kg.		per ton
1	Conversion of Cropland to Grass/Hay	$ 55.31	$ 18.88	$ 34.56
2	Fert. Mgt. - 25% reduced P application	$ 441.45	NA	NA
3	Establish Filter Strips	$ 6.39	$ 2.66	$ 3.64
4	Establish Grassed Waterways	$ 9.65	$ 24.54	$ 4.60
5	Terracing	$ 53.39	$ 23.81	$ 29.85
6	Prescribed Grazing	$ 215.65	$ 200.37	$428.01
7	Pasture Planting - reseeding	$ 209.35	$ 194.51	$415.49
8	Critical Pasture Planting - shaping	$1,005.37	$ 53.75	$489.06
9	Grade Stabilization - gully plugs	$ 14.92	$ 3.50	$ 8.10
10	Prescribed Burning	$ 72.62	$ 42.87	$ 69.37
11	Brush Management	$ 285.78	$ 265.53	$257.81
12	Phase II Urban Stormwater BMPs	$ 421.33	NA	$491.90
13	Voluntary Urban Nutrient Mgt.	$ 389.18	$ 83.89	NA
14	Required Urban Nutrient Mgt.	$ 27.06	$ 32.33	NA
15	Herbicide Application - Riparian corridor	$ 15.37	$ 14.28	$ 13.87
16	Riparian Buffer Strips - Med Erosion Areas	$1,431.70	$ 313.00	$ 81.54
17	Riparian Buffer Strips - Critical Areas	$ 998.83	$ 201.57	$ 65.24
18	Wetland Development - West Fork Trinity	$ 298.97	$ 32.45	$ 87.58
19	Wetland Development - Walnut Creek	$ 538.23	$ 94.71	$197.49
20	Hypolimnetic Aeration	$ 62.43	NA	NA
21	P Inactivation with Alum	$ 110.92	NA	NA
22	WWTP - Level I to Level II	$ 416.69	NA	NA
23	WWTP - Level I to Level III	$1,153.13	$2,306.26	NA
24	Flood Protection Sites - Big Sandy/Salt Creek	$ 204.82	$ 173.31	$180.24

Table 7. Ranking of BMPs by Lowest Estimated Annual Cost for Reduction of Total Phosphorous Inflow into Eagle Mountain Lake.

Ranking of BMPs by Lowest Estimated Cost		
BMP	Description	Annual Cost per kg. of Total P reduced
3	Establish Filter Strips	$ 6.39
4	Establish Grassed Waterways	$ 9.65
9	Grade Stabilization - gully plugs	$ 14.92
15	Herbicide Application - Riparian corridor	$ 15.37
14	Required Urban Nutrient Mgt.	$ 27.06
5	Terracing	$ 53.39
1	Conversion of Cropland to Grass/Hay	$ 55.31
20	Hypolimnetic Aeration	$ 62.43
10	Prescribed Burning	$ 72.62
21	P Inactivation with Alum	$ 110.92
24	Flood Protection Sites - Big Sandy/Salt Creek	$ 204.82
7	Pasture Planting - reseeding	$ 209.35
6	Prescribed Grazing	$ 215.65
11	Brush Management	$ 285.78
18	Wetland Development - West Fork Trinity	$ 298.97
13	Voluntary Urban Nutrient Mgt.	$ 389.18
22	WWTP - Level I to Level II	$ 416.69
12	Phase II Urban Stormwater BMPs	$ 421.33
2	Fert. Mgt. - 25% reduced P application	$ 441.45
19	Wetland Development - Walnut Creek	$ 538.23
17	Riparian Buffer Strips - Critical Areas	$ 998.83
8	Critical Pasture Planting - shaping	$1,005.37
23	WWTP - Level I to Level III	$1,153.13
16	Riparian Buffer Strips - Med Erosion Areas	$1,431.70

Table 8. The Suite of Cost-Efficient Best Management Practices that Achieves the 30 Percent Target Reduction of Total Phosphorous (P) Inflow into Eagle Mountain Lake.

		Initial Estimated Standards				
		Total P	Total N	Sediment		
		173,020 kg.	1,055,220 kg.	296,400 tons		
		Cumulative Reduction Percentages				
BMP	Description	Total P	Total N	Sediment	Cumulative Net Present Value	Cumulative Annuity Equivalent Value
3	Establish Filter Strips	3.9%	2.3%	5.7%	$ 728,542	$ 35,083
4	Establish Grassed Waterways	5.7%	2.3%	5.7%	$ 836,071	$ 40,261
9	Grade Stabilization - gully plugs	7.8%	3.5%	7.0%	$ 1,372,284	$ 66,083
15	Herbicide Application - Riparian corridor	8.5%	5.6%	9.6%	$ 1,419,229	$ 68,344
14	Required Urban Nutrient Mgt.	12.3%	6.1%	8.1%	$ 4,394,499	$ 211,619
5	Terracing	14.0%	6.3%	8.5%	$ 5,698,866	$ 274,431
1	Conversion of Cropland to Grass/Hay	20.5%	7.2%	10.6%	$13,250,797	$ 638,098
10	Prescribed Burning	21.3%	7.3%	10.8%	$13,438,671	$ 647,145
21	P Inactivation with Alum	24.6%	7.3%	10.8%	$26,391,272	$1,270,883
24	Flood Protection Sites - Big Sandy/Salt Creek	28.8%	12.3%	14.9%	$58,771,313	$2,830,158
7	Pasture Planting - reseeding	29.1%	12.4%	15.0%	$59,410,655	$2,860,946
6	Prescribed Grazing	29.1%	12.4%	15.0%	$62,045,060	$2,987,807
11	Brush Management	29.4%	11.1%	15.3%	$65,536,134	$3,155,921
18	Wetland Development - West Fork Trinity	31.3%	14.7%	20.0%	$95,183,982	$4,583,626
	TOTALS	31.3%	14.7%	20.0%	$95,183,982	$4,583,626

Table 9. The Suite of Cost-Effective Best Management Practices that Approach the 30 Percent Target Reduction of Total Phosphorous (P) Inflow into Eagle Mountain Lake.

		Initial Estimated Standards				
		Total P 173,020 kg.	Total N 1,055,220 kg.	Sediment 296,400 tons		
		Cumulative Reduction Percentages				
BMP	Description	Total P	Total N	Sediment	Cumulative Net Present Value	Cumulative Annuity Equivalent Value
3	Establish Filter Strips	3.9%	2.3%	5.7%	$ 728,542	$ 35,083
4	Establish Grassed Waterways	5.7%	2.3%	5.7%	$ 836,071	$ 40,261
9	Grade Stabilization - gully plugs	7.8%	3.5%	7.0%	$ 1,372,284	$ 66,083
15	Herbicide Application - Riparian corridor	8.5%	5.6%	9.6%	$ 1,419,229	$ 68,344
14	Required Urban Nutrient Mgt.	12.3%	6.1%	8.1%	$ 4,394,499	$ 211,619
5	Terracing	14.0%	6.3%	8.5%	$ 5,698,866	$ 274,431
1	Conversion of Cropland to Grass/Hay	20.5%	7.2%	10.6%	$13,250,797	$ 638,098
10	Prescribed Burning	21.3%	7.3%	10.8%	$13,438,671	$ 647,145
21	P Inactivation with Alum	24.6%	7.3%	10.8%	$26,391,272	$1,270,883
24	Flood Protection Sites - Big Sandy/Salt Creek	28.8%	12.3%	14.9%	$58,771,313	$2,830,158
7	Pasture Planting - reseeding	29.1%	12.4%	15.0%	$59,410,655	$2,860,946
6	Prescribed Grazing	29.1%	12.4%	15.0%	$62,045,060	$2,987,807
11	Brush Management	29.4%	11.1%	15.3%	$65,536,134	$3,155,921
13	Voluntary Urban Nutrient Mgt.	29.9%	11.5%	15.3%	$71,611,742	$3,448,495
	TOTALS	29.9%	11.5%	15.3%	$71,611,742	$3,448,495

Watershed Area Suitable for BMP

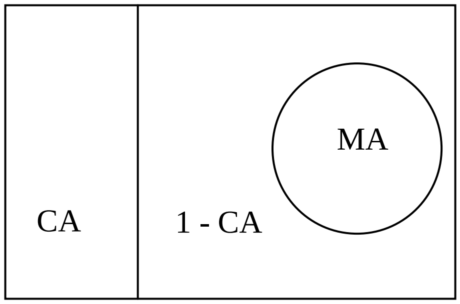

Figure 1. Illustration depicting marginal adoption (MA) area as a subset of the area (1 - CA) in which a Best Management Practice (BMP) is not currently adopted (CA).