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Reducing Agricultural Water Pollution in Texas: An Application of Linear Optimization

Kent D. Messer
Editor

Case Study
By
Lenna Hildebrand
Stephen Stark

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Abstract

Linear optimizations models have been used for many practical purposes throughout the years – maximization and minimization models have proved to be key tools when striving to reach a goal. This case study employs such a model with the goal of maximizing an approximate reduction of pollutant loads from individual parcels per year with the implementation of BMPs throughout Fort Bend, Texas. The motivations for this study are the ever growing levels of Nitrogen, Phosphorus and sediment pollutant levels throughout the San Bernard Watershed, in which Fort Bend belongs. To do this, several BMPs related to livestock pollutant loads are examined and selected to be included in the model. This model will choose BMP and parcel combinations in order to provide maximum potential pollutant reductions for each parcel. As a result we obtained 32 BMP implementation recommendations across 31 parcels for a maximum reduction in pollutant loads of roughly 4.3 million pounds per year. A parameter analysis on the maximum budget concluded that the budget could increase until approximately $6 million where it begins to level off at 65 million pounds of pollutant reduction per year. There are several opportunities to expand this research, including developing a watershed wide model.

For additional information regarding these case studies or the APEC 807 course, contact:

Kent D. Messer, PhD
531 S. College Avenue, #226
Department of Food & Resource Economics
University of Delaware
Newark, Delaware 19716
messer@udel.edu
(302) 831-1316

Reducing Agricultural Water Pollution in Texas: An Application of Linear Optimization.

Lenna Hildebrand, Stephen Stark

1. Introduction

Throughout the United States there are thousands of channels, streams, rivers and lakes that all drain into watersheds that provide citizens with their drinking water, places for recreational activities, as well as substance for many other purposes including agriculture. Currently, due to pollution levels, there are 41,288 registered impaired water bodies throughout the United States and there are continuing signs of increase (USEPA, 2012b). In response, each state has several agencies working along with the Environmental Protection Agency (EPA) to devise water quality management and protection plans to target these problem areas. The state of Texas in particular contains 23 major river basins in which 719 impaired bodies of water can be found (Watershed FAQs, 2012;USEPA, 2012b). This case study focuses on one impaired watershed from Texas in particular, the San Bernard, through the study of data and modeling of BMP implementation in Fort Bend, Texas.

The San Bernard watershed stretches 125 miles long, covering an area approximately 900 square miles (H-GAC,2012). Austin, Colorado, Wharton, Fort Bend and Brazoria counties are all located within this area. Most of the land within these counties is devoted to crop production and cattle grazing, and the river itself is used for boating and fishing. The watershed provides water for a large population which is expected to more than double in the next 30 years, reaching 45,746 by 2040, according to Houston-Galveston Area Council (H-GAC, 2012).

It is important to distinguish why the San Bernard was chosen for this case study. The Texas Commission on Environmental Quality (TCEQ) has placed the San Bernard on its list of impaired waters because portions of the San Bernard River have elevated bacteria levels and do not meet contact recreation standards (H-GAC, 2012). Low dissolved oxygen and excess nutrients like nitrogen and phosphorus also plague the river. The combination of deteriorating water quality and expanding population is proving to be a concern. If the loads of excess nutrients from pollution into the watershed are not reduced, there

could be little hope for the river's water quality levels to return to acceptable levels and still meet demand by its residents.

2. Non-Point Source Pollution

As seen previously, water pollution is a present and growing concern throughout the nation. This pollution is difficult to control due to the vast sources it can originate from (USEPA, 20012a). Water pollution can be divided into two different types – point source, and non-point source pollution. Point source pollution includes pollutants discharged directly into the water byan identifiable source (e.g. waste treatment facility); however, non-point source pollutants are much more complex and difficult to track, control, and remediate (US EPA, 20012a). Federal and state laws regulate point source pollutants, but non-point source pollutants are almost entirely unregulated (Shortle, et al 2012).

Since nonpoint source pollution is a combination of many different pollutants, determining where the pollutants are coming from or who the largest contributors are is difficult. Such sources include: runoff from streets and yards, construction runoff, agricultural sources, and malfunctioning septic systems. The agricultural sector is proving to be one of the leading contributors to in lakes in rivers and accounts for roughly 48 percent of impaired river and stream miles in the US (US EPA, 20012a). Agriculture has also become the third leading cause of impairments to estuaries in the United States (US EPA, 20012a). Some agricultural activities leading to the runoff of nonpoint source pollutants include: plowing crops, applying fertilizers, planting crops, irrigating, applying pesticides, grazing, and confined animal facilities operations (US EPA, 20012a). For example, the impacts of overgrazing include erosion, introducing invasive species, exposing soil, and destroying fish habitats from reduction in water quality (US EPA, 20012a). Bacteria, pathogens, pesticides, nitrogen, phosphorus, and sediment are also major pollutants from the above mentioned sources (US EPA, 20012a).

3. Best Management Practices (BMPs)

In order to combat the polluting effects of agriculture practices, the government and agencies across the nation have joined together to begin implementing watershed quality management plans which consist of several best management practices (BMPs) that farmers can employ. TCEQ defines BMPs as being "practices determined to be the most efficient, practical, and cost-effective measures identified to guide a particular activity or to address a particular problem (2004)." The main difficulty with BMPs is the uncertainty in the BMP's efficiency inreducing pollutants in runoff. There is no exact reduction efficiency of any particular BMP, and it can vary greatly, depending on the land topography and weather in the

area that they are employed. Another difficulty includes the cost of implementing such practices. There is rarely a financial benefit to employing BMPs, and they can be costly. Plans can be devised for free, for land owners, by the Texas State Soil and Water Conservation Board (TSSWCB). However, the practices outlined within the plan are not paid for, but funding may be available.

Currently, there are 152 Water Quality Management Plans (WQMPs) being employed by the TSSWCB through the San Bernard Watershed (H-GAC, 2012). These plans cover 64,383 acres, which is approximately 9% of the total watershed acreage. Implemented with the goal of achieving water pollution prevention and state water quality standards, these site-specific plans include many BMPs like prescribed grazing, forage harvest management, nutrient management, and crop residue management (H-GAC, 2012).

4. Previous studies

Much literature has been focused on tackling the issue of nonpoint water pollution from agriculture. Studies range from modeling approaches to estimating pollutant loads, estimating pollutant reduction benefits from best management practices, to economic analyses of mechanisms to promote implementation of BMPs. The range of the results of these studies is also quite broad. In their study of the Grand Lake St. Mary's watershed in Ohio, J. Hoorman et al (2008) found that excessive phosphorus in water sources contributes to algal blooms and other forms of eutrophication. Using directly collected runoff data from a research farm in Iowa, D.F. Weber et al (2010) studied the effectiveness of vegetative filter strips as well as grazing management practices. No significant difference in average runoff losses among the nine treatment combinations were found, representing the lower bound of the large range of study results. It should be noted that various data collection techniques and methods of study used contributes to the wide range of study results.

B. Evans and K. Corradini (2001)define pasture land management as the utilization of practices that ensure vegetative cover to prevent excessive soil erosion from overgrazing and other types of overuse. This can include rotational grazing, or intensive rotational grazing. Both include rotating livestock and planting hay or legumes as feed for livestock to prevent erosion and fix nitrogen, while the latter involves the use of fencing or paddocks.Estimates for the nutrient reduction efficiency of pasture land management are nitrogen reductions of 43%, phosphorus reductions of 34%, and sediment reductions of 13%(Evans and Corradini, 2001).

Other methods of analysis include those such as G.C. Sigua et al (2006). Using directly collected soil and water data from a farm in Florida, they found that a properly managed mixed agricultural operation

(livestock and crop rotations) may not be major contributors to excess levels of pollutants such as phosphorus and potassium. They observed normal soil fertility levels and "good" (based on the Florida Water Quality Standard) water quality levels in surrounding water bodies. A study conducted by P. Vidon et al (2008) used data from a differently managed farm. Using water quality data directly collected over a 12 month period from a stream section in the Eagle Creek Watershed near Indianapolis, Indiana, they found that in the presence of unrestricted cattle access to streams, total phosphorus levels increased fivefold. In addition, under the same conditions, total suspended sediment levels increased 11-fold.

Other studies use simulation techniques to model the impact of BMP implementation. Using the Soil and Water Assessment Tool (SWAT) model, C. Santhi et al (2006) simulated the implementation of water quality management plans (WQMPs) in the West Fork Watershed in Texas. Some of the BMPs included in the water quality management plan were waste utilization practice, forage harvest management, critical area planting, and brush management, and the reductions were measured as percentage reductions both at the farm level and the sub basin level.

The authors found that implementing these BMPs as well as others could result in ranges of farm level reductions in sediment, nitrogen, and phosphorus of 21-99%, 1-98%, and 1-97%, respectively. Again, these reduction values vary greatly due to the stochastic nature of factors involved.

Other literature focuses on the regulatory environment of the agricultural sector and its role in guiding the reduction of nonpoint source water pollution. According to Abdalla and Lawton (2006), federal oversight of livestock operations in the U.S. has been quite ineffective in dealing with water quality problems associated with animal agriculture. Because of this, state governments have established different strategies and rules, resulting in the relocation of polluting farms to states with less stringent environmental policies. They also suggest that government payments (subsidies, or "green payments") to farms have are a major new direction for agricultural policy.

5. Case Study Specifics

To narrow down the vastness of the case study and due to the limitations of the data available, the focus of the study is on Fort Bend County, a major county found in the watershed. This county covers 861.48 sq. miles (US Census, 2012) and is one of the most dense agriculture areas in the watershed.

With that decided, attention was turned to selecting a segment of agriculture to examine for BMP implementation.

Houston-Galveston Area Council conducted an online survey asking residents and land owners what they viewed as the main causes and sources of pollution within the San Bernard Watershed. OSSFs and Septic Systems were number one, but were closely followed by cattle and then by agricultural lands (H-GAC, 2012). Other questions, such as how much land they have, how they use their land in the watershed, and whether or not they have taken part of the Water Shed Protection Plan Process (H-GAC, 2012) were also included. Due to these findings, it was only natural to select livestock as the nonpoint source to focus on for this case study. Fort Bend is actually considered to be one of the top cattle/calf producers in the state (H-GAC, 2012). Cattle are large producers of bacteria, nitrogen, and phosphorus, and over grazing can lead to heightened sediment pollutant levels. This case study will examine reductions in nitrogen, phosphorus, and sediment levels throughout the county by modeling common BMPs.

Best Management Practices Choice Analysis

When selecting the best BMPs for certain parcels, there are many factors to consider. Some of which include parcel land use, water location within the parcel, cost of implementing the BMP, purpose of the BMP, land topography, weather conditions, and BMP efficiencies. When considering that the case study is only focusing on livestock contribution to pollutants, the vast pool of BMPs can be reduced to only include those pertaining to livestock. After reviewing many options for livestock BMPs from the Natural Resource Conservation Service, the focus was narrowed down to the implementation of watering facilities, prescribed grazing, waste storage facilities, critical area planting and fencing – all of which are approved for both natural and improved pasture lands. The reasons for our selections are listed below. Watering Facilities were chosen because they reduced manure contamination in water sources by keeping animals out of the streams, ponds and other water sources by giving them an alternative water source to drink from (NCRS, 2010).

Prescribed grazing was selected due to its ability to help improve the quality and quantity of vegetation, which will not only reduce soil erosion and sediment pollution but also potentially reduce the need for fertilizers due to controlled grazing practices (NRCS, 2007).

Waste storage facilities were selected because they are used to temporarily store waste, which removes it from being in contact with the land, reducing nitrogen and phosphorus pollution. It however, has no impact on sediment loads (NRCS, 2012).

Critical area planting was chosen due to its ability to help stabilize stream banks, areas with high erosion rates and re-vegetate and rehabilitate sites that cannot be stabilized using normal establishment techniques (NRCS, 2011).

Lastly, fencing was chosen because it enables the user to control where livestock graze and keeps animals out of water sources – thus reducing manure contamination (NRCS, 2008).

In Table 1, featured below, we have displayed the approximated efficiencies for each BMP. BMP efficiencies were found from several sources, including the Chesapeake Bay Program, the Pennsylvania Department of State, the state of Maryland, and the Hampton Roads Planning District Commission (Chesapeake, 2009; Perkinson, 2003; Pennsylvania, 2012; HRPDC, 2011).Since, each site listed different efficiencies, we found the average for each BMP and used those numbers throughout our model.

Table 1. BMP efficiencies

BMP	Nitrogen	Phosphorus	Sediment
Watering Facility	22.5%	26%	56.5%
Prescribed Grazing	13%	21.3%	33.3%
Waste Storage Facility	75%	75%	N/A
Critical Area Planting	65%	78%	76%
Fence	20%	20%	20%

6. Data

The data used for the study is county level GIS data, which includes information on the parcel size in acres, land use, parcel shape, and stream data. Irrelevant data was discarded for analysis efficiency. The two land uses in this data that pertain to livestock are Native or Natural Pasture Land and Improved Pasture Land. Improved pastureland includes pastures that have been managed through different practices including the planting of hay species and other non-native grasses and the use of fertilizer in order to make the land of better quality and more productive. On the other hand, native or natural pasture land has not been improved in any way and is considered typically to be of less quality than improved pasture land, leading to reduced productivity.

To approximate annual loads of nitrogen, phosphorus, and sediment, the EPA developed program called STEPL was utilized. With this program, the land use and animal unit data are input to approximate the loads that each parcel will produce. This program is actually quite extensive and can be used to judge loads of a variety of different nonpoint source pollutants. Before parcel data could be put into the

program, approximate cattle loads for each parcel had to be calculated, as this data is private and is not given by the GIS data set.

Calculating Approximate Cattle Loads

Approximate cattle numbers for each parcel are calculated using the recommended animal units per acre guidelines provided by the Central Appraisal District of Wharton County, Texas. This paper states that for excellent range condition, one AU (animal unit) of cattle (one 1000lb cow)for each1-3 acres of land per year is recommended (Wharton, 2007). Due to the management practices of improved pasture land, excellent condition is assumed, and therefore two acres per animal unit is used for the calculation. In the case of native or natural pasture land, average range condition is assumed, considering that there is less grass coverage and more herbaceous plants, which reduces the quality of the pasture land when compared with improved pastures. The range for average range condition was from 4-8 acres per AU. Four acres per AU is used in order to calculate the proportionate amount of cattle that would be placed on each individual native or natural land parcel.

With the recommended numbers for acres per animal unit, the cattle per acre calculations are as follows:

(1) $$\text{Cattle per acre} = \frac{\text{Parcel acreage}}{\text{Acres per AU}}$$

This calculation produces a total of 43,709 cattle for all of Fort Bend county. When compared to the actual number of cattle in the county as of March 2012, this number is 2,497 less (hgac). This calculation is quite accurate, and is acceptable for the purposes of the study.

Calculating Approximate Total Loads for Nitrogen, Phosphorus and Sediment

The data collected from the cattle number calculations is entered into the EPA STEPL program to approximate total annual loads for nitrogen, phosphorus, and sediment. Other information such as state, county, and weather station are chosen to improve estimation accuracy of the program. The total results are listed in the table below and per parcel contribution is shown in graphs following the table.

Table 2. Estimated Total Loads

	Nitrogen	Phosphorus	Sediment
Total Loads (lb./year)	1,207,453.1	119,407	58,161,413.4

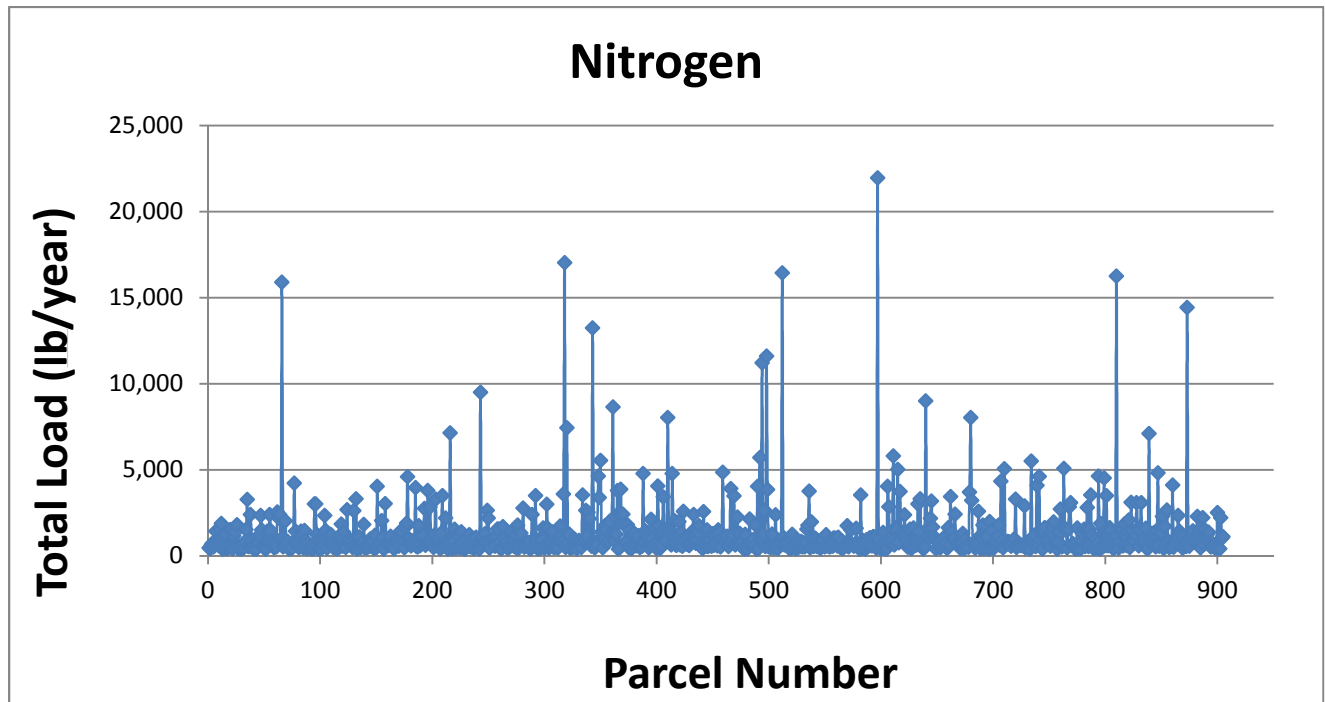**Figure 1. Estimated Nitrogen Loads per Parcel**

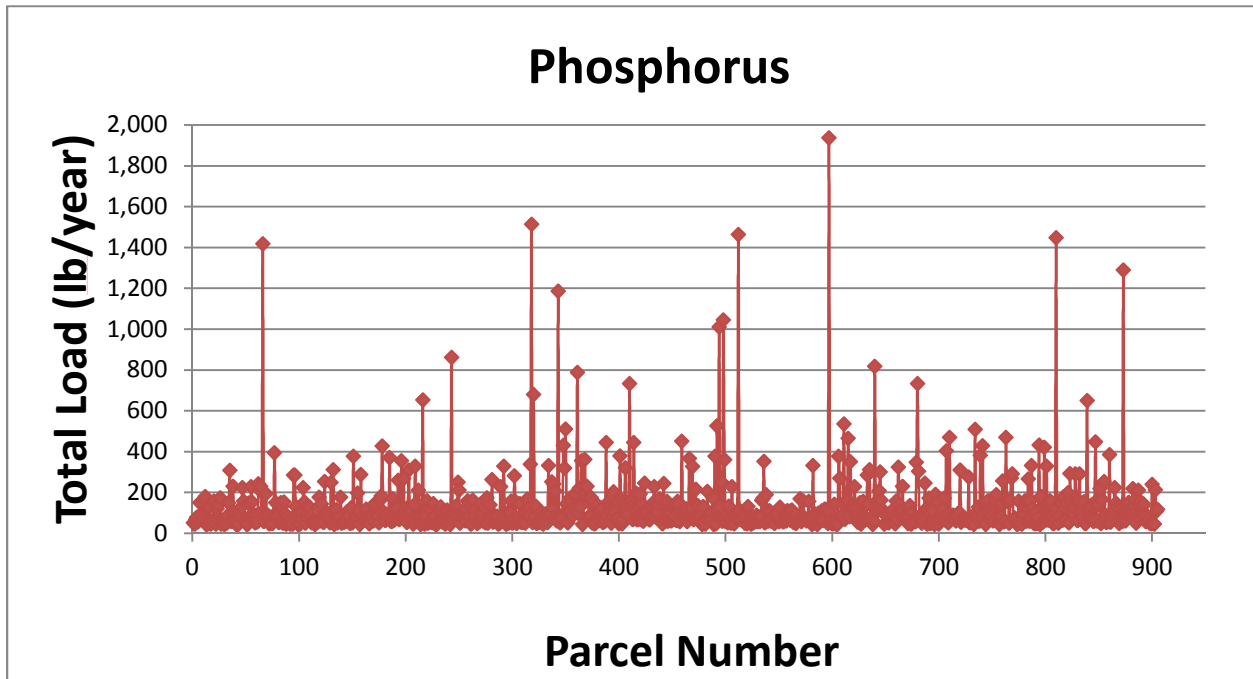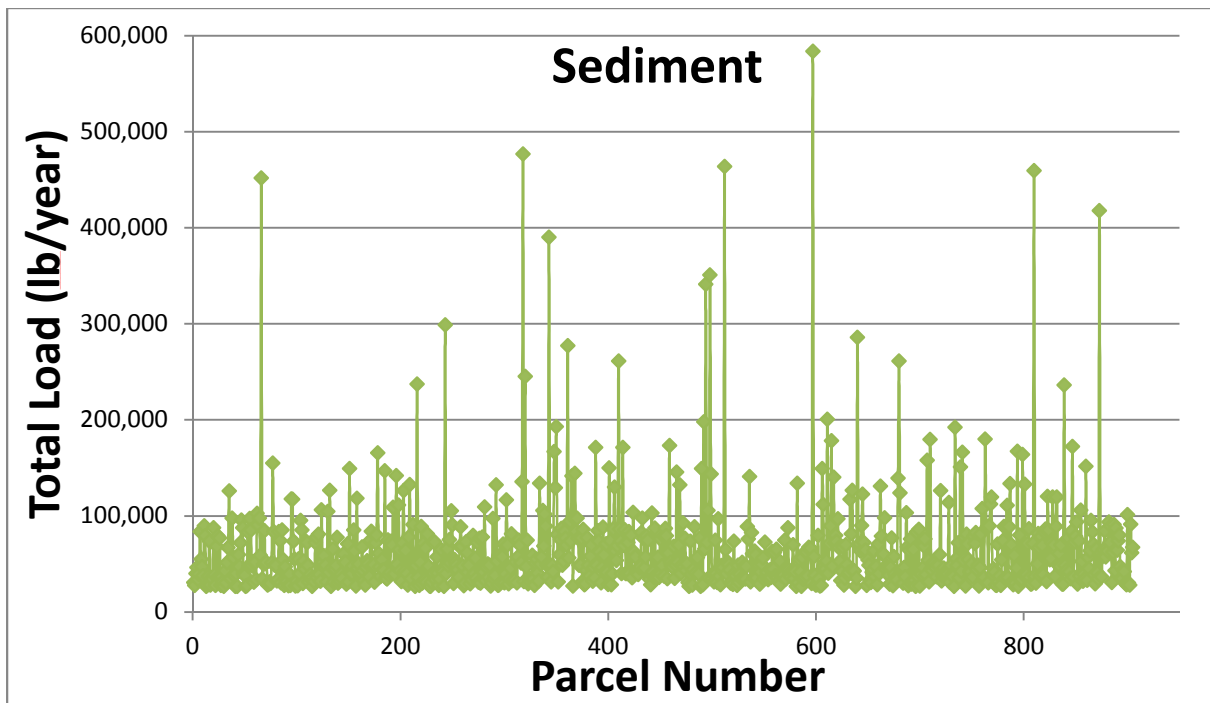**Figure 2. Estimated Phosphorus Loads per Parcel**

**Figure 3. Estimated Sediment Load per Parcel**

Calculating Stream Proximity of Parcels

It is worthy to note that not all parcels are in close proximity of natural water sources. This can influence the BMPs that are implemented within the parcel itself. For instance, two of the chosen BMPs, watering facilities and fencing, depend on water proximity.

Due to this requirement, it is necessary to find out which parcels are in close proximity of water and about how much of the land is within this proximity. For the parcels in close proximity, the dummy variable r will equal one. However, if the parcel is not, then r will equal zero.

The following map, figure 4, is constructed using county level parcel data and region level streams data. A polygon outlining the county border is created and used to clip the streams layer to improve efficiency of analysis.

Figure 4. Map of Parcels of Interest in Fort Bend County
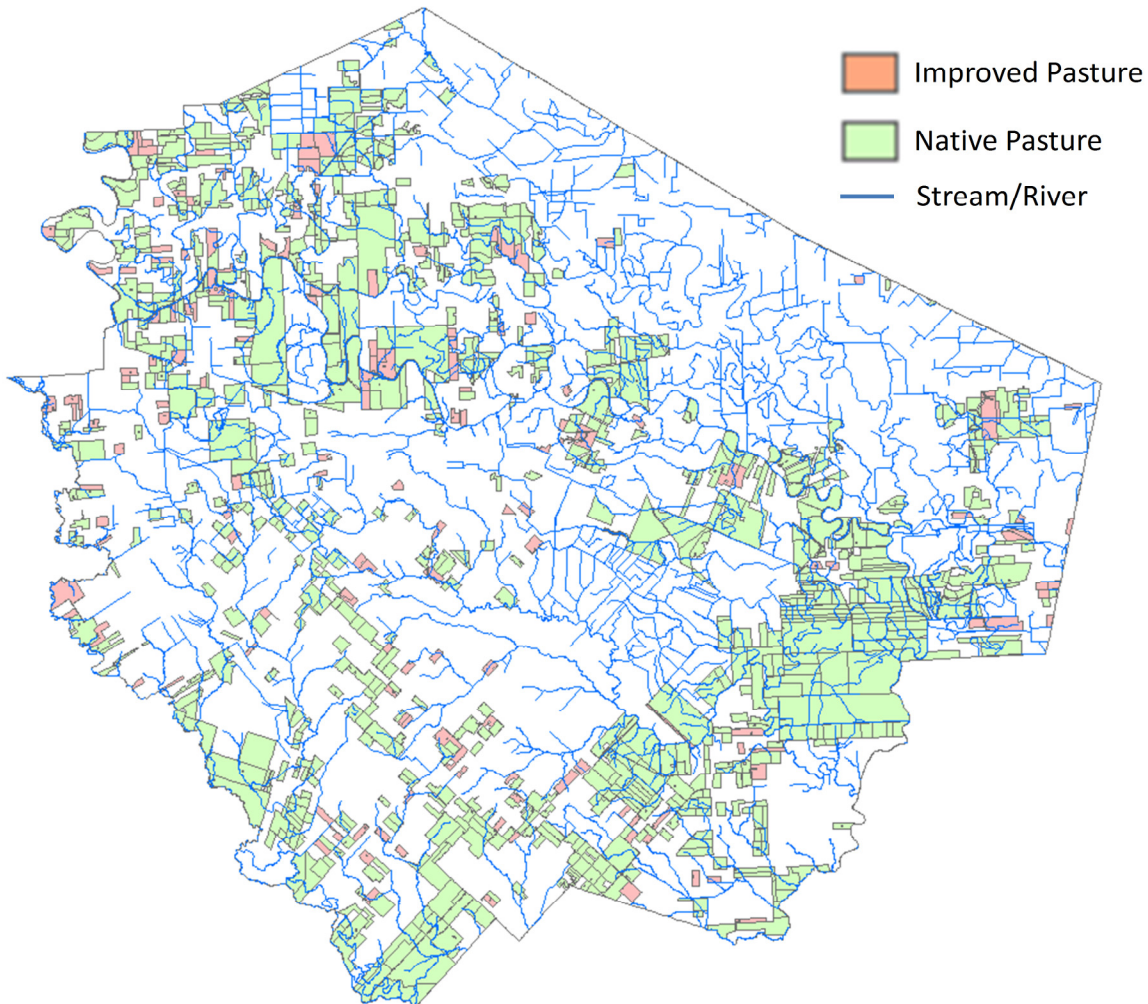
Using the H-GAC streams data and the buffer tool in ArcMap, a 500 foot buffer is constructed on either side of the streams in the data layer to create a measure of stream proximity. The following map, figure 5, shows the results of this process. In this process, a 0/1 dummy variable is created, indicating whether or not any piece of a parcel is within the 500 foot buffer of a water source. This dummy variable is useful in determining whether or not a BMP requiring proximity to a water source can be implemented, such as a watering facility or fencing.

Figure 5. Buffer Zone Located in Parcels

Legend:
- Improved Pasture
- Native Pasture
- Stream with 500 ft. buffer
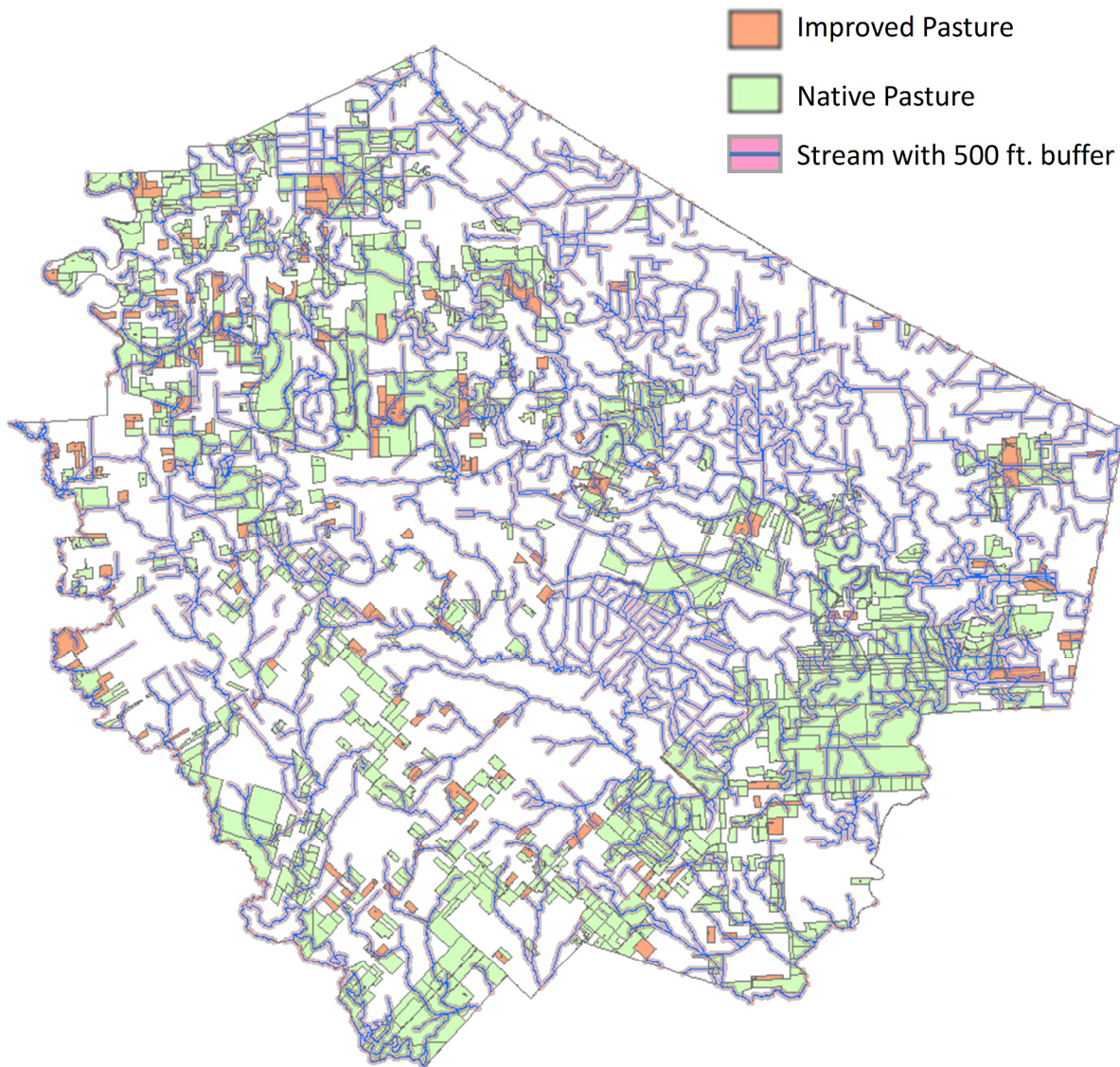
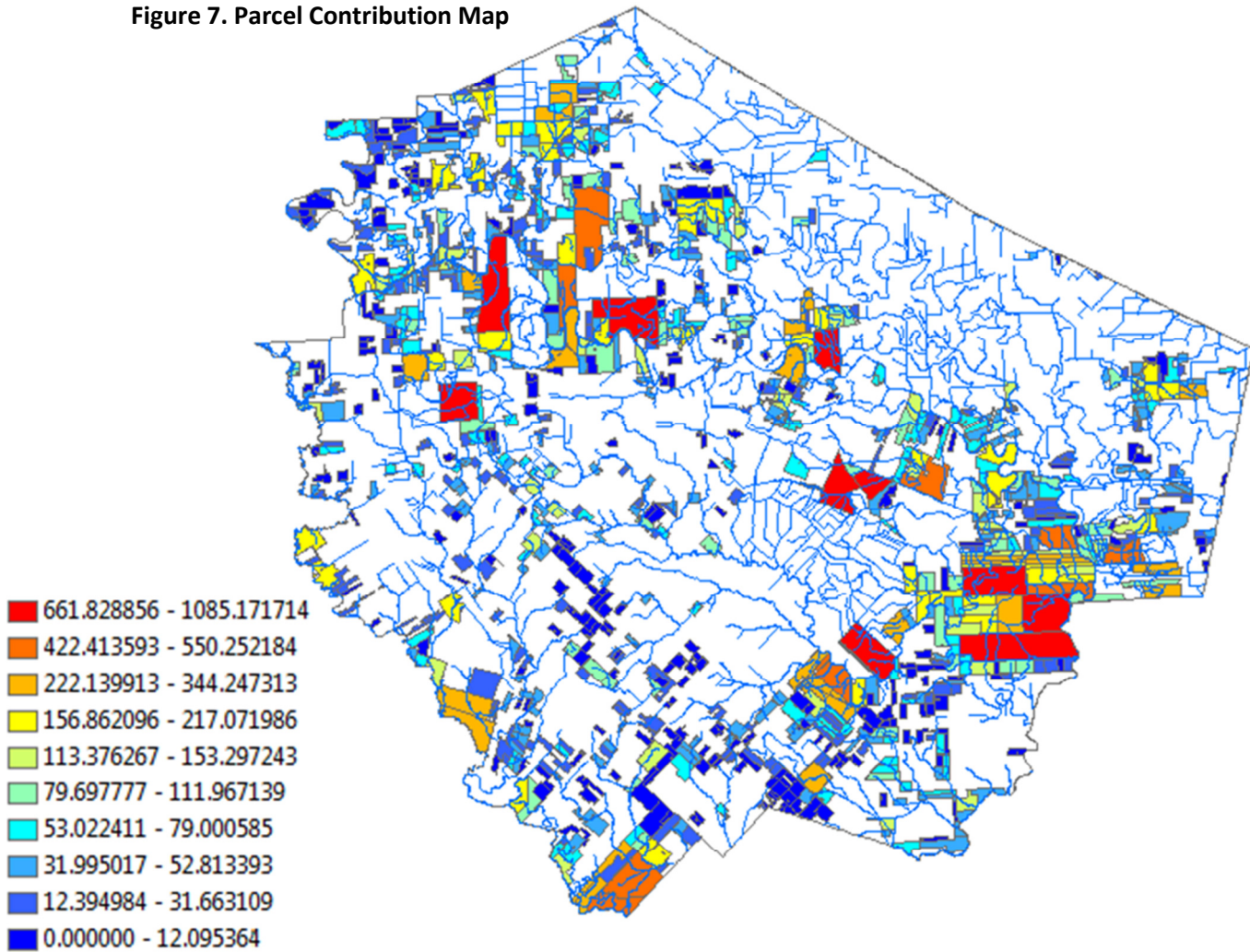The following map, figure 6, is a union map of the stream buffer layer and parcels layer. With this map, a variable is created which is coded with either a 1 or -1 to indicate the pieces of the parcel either within (1) or not within (-1) the 500 foot buffer area. With this, the area in square feet, as well as in acres, is calculated for the pieces of each parcel within the buffer area.

Figure 6. Area of Stream Proximity within Parcel
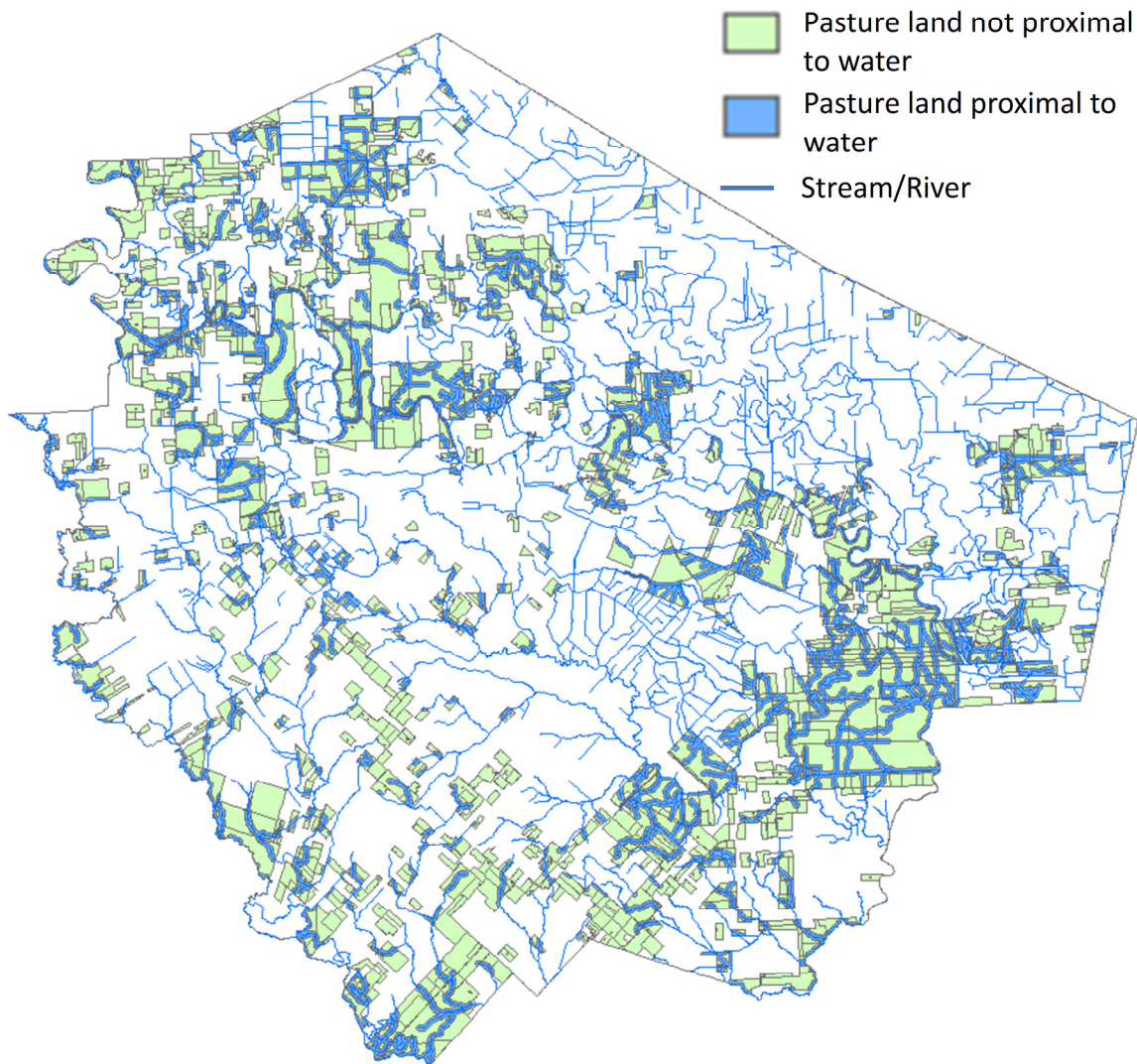
This created a measure of how much land in each parcel is abutting or within close proximity of a water source; a variable useful for determining the amount of fencing to use for the fencing BMP. Another implication of the information displayed in the following map, figure 7, is relative parcel contribution. The greater the area within proximity of a water source, the greater the potential to contribute excess nutrients and sediment to the water source.

Figure 7. Parcel Contribution Map

![red]	661.828856 - 1085.171714
![orange]	422.413593 - 550.252184
![dark orange]	222.139913 - 344.247313
![yellow]	156.862096 - 217.071986
![light green]	113.376267 - 153.297243
![green]	79.697777 - 111.967139
![cyan]	53.022411 - 79.000585
![light blue]	31.995017 - 52.813393
![blue]	12.394984 - 31.663109
![dark blue]	0.000000 - 12.095364

7. The Model

Since there are currently no TMDLs for nitrogen, phosphorus or sediment in the San Bernard Watershed, we employed a binary integer program to maximize Total Load (TL) reductions per year for Fort Bend. This method is utilized because the BMP will either be implemented (1) or not implemented (0) on each parcel of land. More than one BMP can be implemented on a parcel at one time, but the total number of BMPs will be subject to a budget constraint.

For the purpose of the case study we have made several assumptions. For instance, when selecting the parcels to use, we selected only parcels that are 50 acres or more, as larger farms are typically larger contributors to the problem. We have also assumed that each parcel that is used is indeed housing cattle and that none of them are currently empty. For several BMP objective function coefficients,

assumptions as to the proportion of land it is applied to are necessary. Letting C_i^j be the coefficient per BMP per parcel (i= BMP being implied and j=parcel number), shown below are the calculations for each specific BMP objective coefficient.

BMP Objective Coefficients

- BMP1 objective coefficient – Watering Facility

   For this coefficient we assumed that if it is implemented, the benefits would be applied to the total load per year for each pollutant. We then need to multiply it by the water proximity dummy variable (*r)* because this BMP will only be implemented if there is water present. *Below* is the equation to show this.

   (2)
   $$C_1^j = \left[\begin{array}{c} (TL_{Nitrogen}^j \times 0.225) + (TL_{Phosphorus}^j \times 0.26) + \\ (TL_{Sediment}^j \times 0.565) \end{array} \right] \times r$$

- BMP2 objective coefficient – Prescribed Grazing

   For this coefficient, it makes sense to apply it to the entire parcel, and therefore the benefits are applied to the total loads per year for each pollutant. Below is the equation to show this.

   (3) $$C_2^j = (TL_{Nitrogen}^j \times 0.13) + (TL_{Phosphorus}^j \times 0.213) + (TL_{Sediment}^j \times 0.333)$$

- BMP3 objective coefficient – Waste Storage Facility

   Because of the nature of this BMP, the benefit of this BMP is applied to the total loads per year for each pollutant. The following equation is devised to show this.

   (4) $$C_3^j = (TL_{Nitrogen}^j \times 0.75) + (TL_{Phosphorus}^j \times 0.75) + (TL_{Sediment}^j \times 0)$$

- BMP4 objective coefficient – Critical Area Planting

   It is assumed that not all of the acreage within the parcel needs critical area planting. Due to this assumption, it is also assumed that if chosen, this BMP is implemented on only 5 percent of the parcel. This assumption is derived from the nature of this BMP, being that critical area planting is only implemented on a very small percentage of parcel land. The following equation is used.

   (5) $$C_4^j = ((TL_{Nitrogen}^j \times 0.05) \times 0.65) + ((TL_{Phosphorus}^j \times 0.05) \times 0.78) +$$

$$((TL^j_{Sediment} \times 0.05) \times 0.76))$$

-   BMP5 objective coefficient – Fence

    For this coefficient it is assumed that if a fence is implemented to keep cattle out of the stream or give them limited access, it is applied to the entire stream. This implies that the percent reductions of runoff pollutants into the stream per year are applied to the entire total load for each pollutant. Since this is dependent on if there is contact with a stream, the water proximity dummy variable (r) will also apply. Below is the equation to show this.

    (6) $\qquad C^j_5 = \left[(TL^j_{Nitrogen} \times 0.2) + (TL^j_{Phosphorus} \times 0.2) + (TL^j_{Sediment} \times 0.2) \right] \times r$

The Objective Function

Once all of these have been determined, the actual objective function can be written out as follows.

(7) $\qquad\qquad max: Z = \displaystyle\sum_{i=1}^{5} C^j_i X^j_i \qquad j = 1,2 \dots .905$

With this, the total load reduction per year can be calculated. This objective function would be subject to a binary constraint on the decision variables (X), as well as a budget constraint for Fort Bend. The budget constraint contains each BMP per parcel and its associated BMP budget constraint coefficient. In the following section, the calculation of budget constraint coefficients is laid out. The costs associated with the BMPs are from a provided cost sheet from the NRCS Wharton office and represent the amount (90 percent of the actual total costs of implementation) that can be funded.

Budget Constraint Coefficients

-   BMP1 budget constraint coefficients – Watering Facility

To calculate the budget constraint coefficient for watering facilities, first we had to determine how many gallons the tank needed to be able to hold. According to the USDA, each cattle unit needs to be supplied 15 gallons per day and that four days' worth of water be kept in the trough (NRCS, 2010). To calculate the total gallons required in the trough at one time, we take the total number of cattle multiply

it by 15 and then again by 4. Once we have this data, we can determine the size of the trough that is needed.

Looking at the cost sheets we have been given, and the total requirements of the cattle, we have determined that we are only looking at three different trough sizes: 2,651-4,250 gallons, 4,251-6000 gallons and 6,000+ gallons. Each of these has a different cost: $2,499.85, $2,943.55 and $4,250 respectively. Knowing this, we filtered the data so that each parcel water requirements have a 1 placed in the trough of the appropriate size and a 0 in those that are either too large or inadequate. We multiply the costs by these dummy variables ($d_1, d_{2,and} d_s$) and add them together to get the coefficient for watering facilities for that parcel. The equation showing this process is below.

$$(8) \qquad a_1^j = \left[\left(d_1^j \times \$2,499.85\right) + \left(d_2^j \times \$2,943.55\right) + \left(d_3^j \times \$4,250.00\right)\right]$$

- BMP2 budget constraint coefficients – Prescribed Grazing

This budget constraint coefficient is easier to calculate. Since we are assuming that it is applied to every acre (l) of the land, we take the cost per acre multiply it by total acres in the parcel. This results in the following coefficient equation:

$$(9) \qquad\qquad\qquad\qquad a_2^j = (l \times 7.50)$$

- BMP3 budget constraint coefficients – Waste Storage Facility

According to the USDA, minimum tank requirements are 15 gallons per day per cow (NRCS, 2002). It goes on to state that the tank should be able to hold 4-7 days' worth of waste in order to allow for some flexibility. For this study, 5.5 days is chosen which is the average between the two numbers. Multiplying the number of cattle by 15 and then again by 5.5 gives the total recommended capacity of the waste storage facility. The cost per gallon of a small storage tank is $1.63. Multiplying this cost by the recommended capacity gives a total cost for the storage tank for the parcel it is being implemented on. Let w equal the number of cows. Below is the equation showing this.

(10) $$a_3^j = (w \times 15 \times 5.5) \times \$1.63$$

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- BMP4 budget constraint coefficients – Critical Area Planting

As previously stated, if critical area planting is implemented, it is only applied to 5 percent of the total acreage. Therefore, this cost coefficient is simply the total acres in the parcel, multiplied by .05 and then multiplied by the cost per acre. Below is the equation.

(11) $$a_4^j = (l \times .05) \times \$63.79$$

- BMP5 budget constraint coefficients – Fence

For this budget constraint, we begin by taking the square root of the area of the parcel within 500 feet of the water source (which is given in sq. feet) in order to calculate the approximate stream length (m). After observing the data maps, this is determined to be a reasonable estimate of the fence needing to be implemented, as not all of the parcels have the stream running directly through it. This number is then multiplied by $1.82 (per foot cost) to get the approximate price for implementing fencing along the stream bed. The equation is modeled below.

(12) $$a_5^j = (\sqrt{m}) \times \$1.82$$

Budget Constraint

Once these are calculated, the following budget constraint can be comprised.

(13) $$\sum_{i=1}^{5} a_i^j X_i^j \leq \$105,601 \qquad j = 1,2 \dots .905$$

The budget for this case study has been approximated to be $105,601 by taking the most recent year's budget from the Environmental Working Group website (2012) due to incomplete data on such budgets. This constraint is not the only constraint on the problem. The next constraint that needs to be factored in is the Watering Facility and Fence Constraint.

Watering Facility and Fence Constraint

This constrain is very simple and straight forward. If fencing is implemented in a parcel to keep cattle out of the stream, some sort of watering facility must be developed in order to provide a source of water for them to drink. Below is the constraint. X_1 is the decision variable for watering facilities and X_5 is the decision variable for fencing.

$$(14) \qquad\qquad X_1^j \geq X_5^j$$

Solving Our Model

After developing the objective function and establishing all the constraints, the excel Premium Solver Platform is used to solve the model for the optimal solution. Premium Solver proved to be the best choice in order to handle the 4,525 decision variables in the model. We ran it with the LP Quadratic Engine, assuming non-negativity and an integer tolerance set at 0. The following section discusses our results.

8. The Results

The model produced an optimal solution given the parameters and constraints. There were 32 BMP implementation recommendations, across 31 parcels of land. Of these 32, 24 were watering facilities, 7 were prescribed grazing practices and 1 was a fence. It is worth noting that one parcel had two BMPs implemented on it – a fence and a watering facility. This is reasonable considering the constraint that if a fence were to be implemented, a watering facility would need to be installed. The total reduction in pollutants is recorded as 4,306,573.373 pounds per year.

The number of parcels with recommended BMP implementation seems rather low, but this is due to the low budget constraint, which will be examined in greater detail within the Budget Parameter Analysis in the next section. On the following page a table, table 3,is displayed that shows the number of implementations and total load reductions per BMP, followed by another table, table 4, with information on the parcels where the BMPs were recommended.

It is worth noting that all the parcels where prescribed grazing is recommended are smaller parcels typically ranging in the mid to high 50's in acreage. In contrast, the parcels in which a watering facility is recommended are rather large, ranging from 500 to almost 3,000 acres each. The fact that so many watering facilities were recommended may be partially due to limited cost data. The largest tank that we had a cost for was a 6000+ gallon tank, which would be needed for such large farms. There was only one price for tanks that were able to hold that much water, but in reality the cost would continue to rise

with an increase in tank size. If more accurate cost data for such large troughs could be found, then the distribution of the money over BMPs and parcels may change and become more evenly distributed. Having the next largest number be prescribed grazing seems rational considering that it contributes a decent reduction of pollutants while also remaining as one of the least costly BMPs to implement. Due to this, we would expect this to be one of the more frequent BMPs to be recommended and implemented throughout the county. Overall, with the focus on quality vegetation and animal health, this BMP provides a rounded approach to addressing the pollutant runoff issue in the San Bernard Watershed.

Below is a chart listing the three pollutants and their total estimated reductions generated from the model if these BMPs are implemented.

Table 5. Total Reductions per Pollutant

Pollutant	Nitrogen	Phosphorus	Sediment
Total Reduction (lb./yr.)	55221.52162	5773.856021	4245577.996

Even though these were the only BMPs that were recommended for implementation, it does not mean that the others are not worth looking into more in depth to find the best situations for them to be implemented in.

Table 3. Total Load Reductions per BMP

BMP	Number Implemented	Total Reduction(lb./yr.)
Water Facility	24	4206063.492
Prescribed Grazing	7	68570.228
Fence	1	31939.653
TOTAL	32	4306573.373

Table 4. Total Load Reductions per Parcel

Parcel ID	Acres	Estimated Cattle	BMP	Total Reduction(lb./yr.)
66	2155	539	Water Facility	259230.7659
77	565.21	141	Water Facility, fence	120610.55952
216	959.1993	240	Water Facility	135849.1341
243	1280	320	Water Facility	171205.682
318	2308	577	Water Facility	273704.9601
320	1000	250	Water Facility	140471.8745
343	1790	448	Water Facility	223714.436
350	741.6	185	Water Facility	110433.1395
361	1165.61	291	Water Facility	158844.1466
410	1081.744	270	Water Facility	149615.3784
492	765.35	191	Water Facility	113276.2844
494	1512.74	378	Water Facility	195648.3303
498	1566.29	392	Water Facility	201151.893
512	2228.51	557	Water Facility	266213.1406
597	2984.858	746	Water Facility	335327.7437
611	778	195	Water Facility	114783.1269
640	1212	303	Water Facility	163887.4324
680	1081	270	Water Facility	149532.8375
710	678.3955	170	Water Facility	102772.5401
734	738	185	Water Facility	110000.5411
763	679.582	170	Water Facility	102917.6689
810	2202.05	551	Water Facility	263705.9314
839	954.6539	239	Water Facility	135331.5882
873	1953.16	488	Water Facility	239774.0101
72	53.22	13	Prescribed Grazing	9427.693401
267	55.8	14	Prescribed Grazing	9826.748206
304	56.056	14	Prescribed Grazing	9866.217771
323	55.7922	14	Prescribed Grazing	9825.545265
378	55.723	14	Prescribed Grazing	9814.872107
792	56.56	14	Prescribed Grazing	9943.858198
808	56.05	14	Prescribed Grazing	9865.29296

Budget Parameter Analysis

The main constraint for the model is the budget constraint. As mentioned before, the budget is approximated to be $105,601. However, on the EWG website it states that there may be incomplete data, and due to this we can assume that the budget is much higher than this. In light of this statement, it is of interest to see what type of returns could be achieved under larger budgets.

To do this, we set up a PsiOptParam option ranging from $100,000 to $10,000,000 for the maximum budget. It was constructed to give approximately $100,000 intervals, so that we could see the general trend of the maximum total reduction over a series of $100,000 increments. The chart below shows us the results.

Figure 8. Budget Parameter Analysis
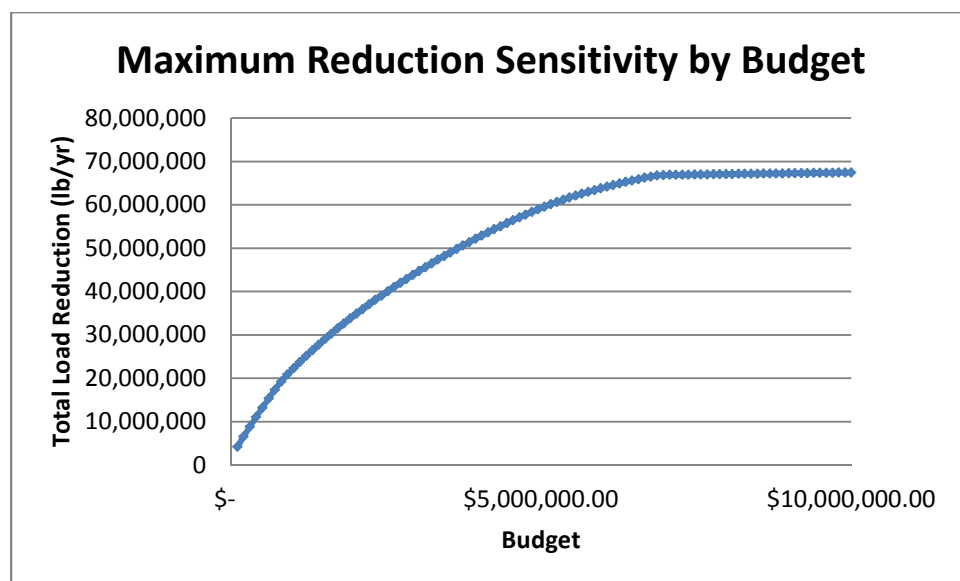
It is rather easy to see that in the beginning, the maximum total reduction increases rapidly with each $100,000 increment. However, as the budget gets closer to $10,000,000 the curve begins to level out, showing a logarithmic shape. Basically, it is beneficial to increase the budget for funding such BMP implementation, but around approximately $6,000,000 it begins to level out and produce roughly the same total maximum reduction in pollutant loads. This gives an estimate of roughly 65 million pounds of total pollutant reduction per year which is approximately 61 more million pounds than our current maximum reduction for the model.

9. Conclusion

The purpose of this case study is to examine BMPs relating to livestock pollutant loads for potential implementation in individual parcels and the estimated total maximum reduction of pollutants within the San Bernard Watershed. It was found, that out of the five BMPs studied, only three were recommended for implementation on 32 parcels of property. This produced a maximum reduction of approximately 4.3 million pounds per year, due to a budget constraint as well as a watering facility and fence constraint.

This study helped to examine which BMPs are more beneficial to be implemented and which parcels are more suited to implement those BMPs on. Such information could be used as a guideline to select the best parcels and BMPs to implement on those parcels. In the long run, such guidelines can help some counties use optimization to recognize their potential for improving water quality on a county level and contributing to the overall general quality of the San Bernard Watershed.

There are many options for further research in this topic. One such option is to study the impact of BMP reduction efficiency estimates on the results of the model. These reduction efficiencies are estimates which can vary greatly in reality due to many factors such as rainfall, land slope, and soil type. Another research area to be pursued involves employing different types of optimization models. For instance, in the presence of a TMDL, goal programming can be used to minimize positive deviations from the established nutrient reduction goals. There are currently no TMDLs for nitrogen, phosphorus, or sediment in the San Bernard Watershed. The model used can also be extended to include other types of agricultural land uses. Such an analysis is beyond the scope of this case study. With large levels of complete data, this type of study can be conducted at the watershed level to paint a more aggregated picture of the problem in a particular region. Such a study would require multi-county data while excluding data from parcels outside of the watershed. As a final suggestion for further research, USGS GIS data could be employed to perform watershed analysis in the region of study to either validate assumptions or provide additional information to factor into the analysis.

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