A GIS-Based Habitat Restoration and Preservation Prioritization Tool Geospatially Integrating Hydrological, Ecological, Pollution, Economic, Social and Cultural Considerations

Te Kipa Kepa Brian Morgan
Ngati Makino Iwi Authority

Dan C. H. Hikuroa
University of Auckland

Proceedings of The National Conference
On Undergraduate Research (NCUR) 2011
Ithaca College, New York
March 31 –April 2, 2011

A GIS-Based Habitat Restoration and Preservation Prioritization Tool Geospatially Integrating Hydrological, Ecological, Pollution, Economic, Social and Cultural Considerations

Brian C. Peacock
Civil and Environmental Engineering
Lafayette College
111 Quad Dr.
Easton, PA 18042 USA

Advisor: [1]Te Kipa Kepa Brian Morgan and [2]Dan Hikuroa

[1]Faculty of Engineering
[2]Institute for Earth Science and Engineering
University of Auckland
Private Bag 92019, Auckland Mail Center
Auckland 1142, New Zealand

Abstract

Riparian wetland buffers (RWBs) are a low cost solution to water quality and runoff management issues. The placement of RWBs within a watershed must be optimized to minimize cost, social impacts and cultural impacts whilst maximizing environmental benefits including nutrient removal, erosion protection, sediment removal, stream temperature regulation, flood buffering, large woody debris sourcing, habitat connection and biodiversity enhancement. This project has developed a land score system for siting RWBs using the cost-benefit analysis framework. Unlike other buffer placement models, this technique does not assume that buffers will be placed adjacent to known streams. Instead, benefits were assessed using a combination of several quantitative metrics: terrain-landuse analysis to identify areas of high areal pollutant flux; distance from streams to encompass riparian functions such as stream temperature regulation, large woody debris and streambank erosion; minimum cost corridor delineation to assess habitat connectivity; and the Mauri Model decision-making framework to account for human factors often difficult to quantify including social, cultural, environmental and economic factors. The result is a simple, flexible wetland-siting tool that utilizes readily available data and can easily be implemented by land planners in a variety of watersheds. This decision making tool was applied to the Tarawera Watershed in the Bay of Plenty, New Zealand to delineate optimal areas for riparian wetland restoration. The metrics used in this tool proved effective in anticipating ecological, hydrological, geological, environmental and anthropologic constraints. The final result was a detailed map indicating areas best suited for buffer placement. In addition, the broad incorporation of weighting factors, defined on a per-project basis allows the technique to yield to different management goals and geographic locations while still maintaining a scientific decision making framework.

Keywords Habitat Restoration, Habitat Preservation, Riparian, GIS, Buffer, Mauri Model

1. Introduction

Riparian buffers are common Best Management Practices (BMPs) for contaminated runoff treatment and management. Riparian buffers are concentrated sources of ecological benefit relative to their areal extent[1]. Riparian restoration aims to restore the ecological functions of stream bank ecosystems including[2, 3]:

1. Reduction of nutrients including nitrogen and phosphorous in runoff[4, 5, 6, 7, 8].
2. Reduction of sediment loading in streams by preventing erosion[9, 10, 11] and trapping sediments[12]. In addition, phosphorous is often transported in sediment, thus trapping these sediments prevents phosphorous from entering streams[13, 14].
3. Support high biodiversity[15, 16, 17].
4. Provide corridors for species dissemination and movement that is essential to sustain populations in highly impacted regions[18, 19, 20].
5. Source of large woody debris (LWD) to streams which provides habitat for aquatic fauna, traps inorganic sediment and stores organic matter[21, 22].
6. Stream temperature regulation[23, 24, 25, 26]. Temperature regulation is important for maintaining high dissolved oxygen and controlling pathogens[26].
7. Buffer flood events[27].

According to Schlosser[28], Kauffman et al.[29] and Crumpton[30], watershed scale riparian management is necessary in order to see large gains in environmental and water quality. Because financial resources for riparian restoration are typically less than what is required to restore all sites within a watershed, spatial prioritization is necessary to choose restoration areas[31]. Placement of riparian buffers at the watershed scale remains a topic of needed research[30, 32].

Because of its simplicity, the most prevalent method for buffer placement is delineation a fixed distance from streams. However, determination of buffer width presents a difficult decision to policy makers who are rarely versed in the scientific peculiarities of buffer placement[33]. As a result, buffer width is either delineated arbitrarily, politically or by educated guess[34]. Additionally, fixed-width riparian buffers fail to account for spatial differences in hydrology, ecology, land use, economics and culture [33, 35]. Because of these limitations, fixed-width buffers do not afford maximum protection of streams[36].

The alternative to fixed-width buffering is prioritization of sites through physical models and decision support tools. In order to rank sites for restoration or preservation, Hyman and Leibowitz[31] propose that the projected marginal change in ecosystem benefit must be compared to the projected marginal change in restoration effort. This paradigm is analogous to cost-benefit analysis, a common decision making framework[31]. However, while benefits typically are expressed in monetary terms in the cost-benefit framework, the benefits of riparian buffers are not as easily expressed this way[31]. The method used by Hyman and Leibowitz has been applied successfully by[37].

Often, complex scientific models are difficult to implement because of extensive data and computation requirements. Methodical simplicity is therefore a key element in a successful riparian buffer placement tool. Educated assumptions and substitution of empirical models for intricate physical models can simplify complex models. While these simplifications relieve intense data requirements, they often add a multitude of constants and weighting factors. Definition of these values is difficult to perform scientifically because they do not represent fundamental constants. Because the goals of RWB projects vary, definition of these constants by estimation serves to better define these restoration goals in the output of the decision support tool. However, in order to be effective a decision making tool, the values of these constants must be decided on by all parties involved in the project. Morgan[38] provides methods for this type of group decision-making which are beyond the scope of this paper.

2. Methodology

2.1 Study Site

The Tarawera Watershed is a catchment of 980 km^2 located in the Bay of Plenty region of New Zealand. The primary anthropogenic influences to this region include:

1. Wetland draining in the lower watershed, causing flooding issues.
2. Land cover within the Tarawera Watershed is 21.51% ‘high producing exotic grassland’ that is used for dairy production[39]. The Runoff from this land-use generally contains high concentrations of nitrogen, phosphorus and fecal coliform bacteria.
3. The Tasman pulp and paper mill uses 260,000 m^3 of water from the Tarawera river daily which, though treated, is released with higher turbidity and likely other contaminants are present downstream of this

discharge point[40]. Adjacent to the plant is a disposal site where mill waste was once dumped that contains a significant amount of toxic material that is leaching into groundwater including: lead, cyanide, zinc, chromium, ammonia, polychlorinated biphenyls (PCBs), dioxins, furans, phenols, chlorine, oil and oxygen demanding waste sludge[41]. There is potential for contaminent trasfer from the site into the river[42].

4. Large portions of the watershed are used for agroforestry of *Pinus radiata* to supply the paper mill with timber.

There are a number of different stakeholders within the Tarawera watershed. Farms, logging operations and the pulp and paper mill are the most significant capitalistic interests that could be affected by riparian buffer implementation. The indigenous Māori people own a large portion of the lands within the watershed. However, their culture dictates treatment of land not as a capital commodity but as a sacred resource to be conserved. The principal of *kaitiakitanga,* best translated as guardianship, strongly influences the land use decisions of the Māori people[43]. Land also has *mauri* or 'life-force' that must be maintained and improved for future generations.

2.2 Data Sources

- 20m topography, exotic vegetation and marae location data was sourced from Land Information New Zealand (LINZ), Wellington, New Zealand.
- Landcost, soil type, prehuman vegetation, geothermal features and historic flooding from a 2004 flood data was obtained from Environment Bay of Plenty (EBOP), Whakatane, New Zealand.
- Surface catchment delineation was produced by Wayne Smith, John Douglas and Michele Hosking for EBOP.
- Landuse was procured from The New Zealand Ministry for the Environment, Wellington, New Zealand, 2002 Land Cover Database Version 2 (LCDB2). The land classification data was converted from LCDB2 format, to the more common United States National Land Cover Database (NLCD) using the methods developed by Hoefner[39].

2.3 Hydrological And Pollutant Modeling

Terrain analysis[44] was used to analyze hydrology and pollutant transport within the watershed. The wetness factor (W), developed by Beven and Kirkby[45] is an established terrain-based indicator of soil dampness that correlates with natural wetland distribution[46, 47]:

$$W = \ln\left[\frac{A}{T \cdot \tan S}\right] \tag{1}$$

Where A is drainage area of the catchment above the point of interest*,* T is the local soil transmissivity and S is the slope angle. This factor has successfully been applied to riparian buffer placement modeling by Moore et al.[48], O'Neill et al.[49], Russell et al.[50], Qiu[51], and Anderson et al.[52]. In order to reduce data requirements, soil transmissivity was neglected by Russell et al.[50] and O'Neill et al.[49] and will be in this study. While this model was intended for wetland identification, it is appropriate for this study because wetland environments are adept at removing a variety of contaminants[27]. Therefore, these areas should be prioritized for preservation and restoration.

Table 1 – The nominal pollutant scores for varying land uses.

NLCD Classification	NLCD #	Pollutant Score	Selection Criteria
Open Water	11	1	Natural Conditions, Contributes Only Background Contaminants
Deciduous Forest- Native	41		
Evergreen Forest- Native	42		
Mixed Forest- Native	43		
Shrubland- Native	51		
Grassland/Herbaceous- Native	71		
Emergent Herbaceous Wetlands- Native	92		
Bare Rock/Sand/Clay	31	2	Moderate Pollutant Contribution; Approaching Natural Conditions
Deciduous Forest- Exotic	41		
Mixed Forest- Exotic	43		
Shrubland- Exotic	51		
Emergent Herbaceous Wetlands- Exotic	92		
Low Intensity Residential	21	3	High Anthropogenic Pollutant Contribution
Quarries/Strip Mines/Gravel Pits	32		
Transitional	33		
Evergreen Forest- Exotic	42		
Orchards/Vineyards/Other	61		
Commercial/Industrial/Transportation	23	4	Very High Anthropogenic Pollutant Contribution
Grassland/Herbaceous- Exotic	71		
Pasture/Hay	81		
Row Crops	82		

Pollutant source areas can be roughly delineated on the watershed scale using land use data[51]. Although transportation infrastructure and drainage systems can affect transport mechanisms[53, 54], these mechanisms were ignored in this study as is consistent with Qiu[51].

In order to address prioritize areas for restoration, a modified wetness factor that takes into account likely sources of contamination was used:

$$\psi = \overline{P} \ln\left[\frac{A}{\tan S}\right] \tag{2}$$

Where ψ is the pollutant accumulation factor, $\overline{P}$ is the mean nominal pollutant score in the catchment above the point of interest, A is the drainage area of the catchment above the point of interest, and S is the slope angle. The nominal pollutant score (P) for each cell is a function of land classification as shown in Table 1. The drainage area (A) of the catchment above a point was assessed using the eight-direction (D8) flow model presented by Jenson and Domingue[55]. The pollutant accumulation factor is readily computed using the FLOWACCUMULATION function in Spatial Analyst (ArcGIS) with a weighting factor exp(P).

2.4 Cultural Assessment

Quantification of social and cultural impacts of water quality improvement methods is needed to more completely assess the societal impacts of these measures[56]. Because of the difference in values between capitalist society and indigenous people, a decision support tool based on improvement of mauri, called the Mauri Model[38] was used as a metric to assess societal riparian buffer benefits. The model is based on four primary well-beings central to Māori culture: economic, environmental, social and cultural well-being. Typically, a set of metrics is devised to assess each of these well-beings based on the nature of the project. Then, an integer value from -2 to +2, representing change in mauri, is assigned for each metric with 2 representing full restoration of mauri; 1, partial restoration; 0, no change; -1, partial degradation; and -2, complete degradation. To adopt this model to GIS, each value in a data layer such as land use was assigned a value for change in mauri as shown in Table 2. The data incorporated into the Tarawera Watershed Mauri Model evaluation included land cover, historical wetland cover, historical flooding and geothermal features. Although the framework of this model is based on Māori culture, the assessment performed in this study uses metrics that are not exclusive to the Māori people, and therefore represents an even societal assessment[38].

Table 2 -The spatial mauri model assessment criteria. The scoring structure broken down by the influencing layer; then the score for each possible value within that layer is given

	Classification	NLCD #	Economic	Environment	Social	Cultural
Landuse/Exotic	Quarries/Strip Mines/Gravel Pits	32	-2	2	-1	0
	Bare Rock/Sand/Clay	31	0	1	0	0
	Transitional	33	0	1	1	0
	Emergent Herbaceous Wetlands- Exotic	92	0	1	0	1
	Shrubland- Exotic	51	0	2	0	1
	Shrubland- Native	51	0	-1	0	0
	Grassland/Herbaceous- Exotic	71	0	2	0	1
	Grassland/Herbaceous- Native	71	0	0	0	0
	Pasture/Hay	81	-2	2	-1	0
	Row Crops	82	-2	2	-1	0
	Orchards/Vineyards/Other	61	-2	2	-1	0
	Deciduous Forest- Exotic	41	0	2	1	1
	Deciduous Forest- Native	41	0	0	0	0
	Evergreen Forest- Exotic	42	-1	2	0	1
	Evergreen Forest- Native	42	0	0	0	0
	Mixed Forest- Exotic	43	-1	2	0	1
	Mixed Forest- Native	43	0	0	0	0
	Low Intensity Residential	21	-1	2	-2	0
	Commercial/Industrial/Transportation	23	-2	2	-1	0
	Emergent Herbaceous Wetlands- Native	92	Final Land Score = 0			
	Open Water	11	Final Land Score = 0			
Historic Flood	Historic Flood Area	-	2	1	1	1
	Not Historic Flood Area	-	1	0	0	0
Geothermal	Geothermal Site	-	-1	-1	-1	-2
	No Geothermal Site	-	0	0	0	0
Cultural Sites	Cultural Site	-	-1	0	-1	-2
	Not Cultural Site	-	0	0	0	0
Weight		-	30%	30%	20%	20%

The final Mauri Model score for a cell is a weighted average of the four well-beings. The weighting for this depends heavily on one's point of view. A good compromise between western viewpoints and indigenous viewpoints, suggested by Morgan, is 30% economic, 30% environmental, 20% social and 20% cultural. This weighting was used for analysis of the Tarawera Watershed.

2.5 Large Woody Debris, Temperature Regulation And Streambank Erosion Prevention

The three ecological metrics presented above are all assessed independently of known stream locations. However, there are several riparian buffer functions that mandate streamside buffering: large woody debris (LWD) production, temperature regulation and prevention of streambank erosion. These functions will be combined into one score called the riparian function score (R). This score will be based on landuse where there is native vegetation and on historic vegetation where native vegetation is no longer present as to represent the restored state of the watershed. Table 3 presents the scoring functions and justification for these scoring methods is given below.

Table 3 - The scoring formulas used to evaluate the riparian function score (R). Brackets indicate a true/false function where a true statement results in an output of 1 and false an output of 0.

Restored Vegitation	Large Woody Debris		Temperature		Streambank Erosion
Forest	[d < 30m]	+	[d < 20m]	+	[d < 10m]
Wetland	0	+	.5 * [d < 10m]	+	[d < 10m]
Shrubland	0	+	0	+	[d < 10m]
Beach	0	+	0	+	0

According to studies in Alaska[57], Oregon and Washington[58], LWD in streams is sourced only from within 30m of the stream. In addition, production of LWD decreases as distance increases from streams. Finally, LWD production requires forested land. It will be assumed that land will be restored to the historic vegetation type.

Temperature regulation by riparian buffers is dependent on the height and density of vegetation surrounding the stream[24, 26]. Because of this, forested areas are scored highest followed by wetlands then shrublands. Although superior models for temperature regulation are available[24] these models quickly become complex and require additional data.

Streambank erosion is prevented by vegetation of any type present on the banks. Although different types of vegetation can be more effective at bank stabilization, this study assumes that all riparian vegetation is equally effective. The broad vegetation classifications available are not specific enough for a more in depth analysis.

2.6 Financial Cost Estimates

The costs associated with habitat construction and restoration include land cost, demolition, clearing, grading, soil conditioning and planting. In addition, culverts and flow regulation devices are necessary, but lack predictable areal costs. Therefore, these costs are included in the planting costs. The cost determination structure and predicted costs for the Tarawera Watershed are shown in Table 4. Modification costs were sourced from Rawlinsons New Zealand Construction Handbook[59]. Establishment costs were based on Frimpong et al.[60] and Wossink and Osmond[61]. The cost of land was based on rate determining land cost provided by Environment Bay of Plenty. All costs were calculated in New Zealand Dollars. Ongoing maintenance costs and opportunity cost (foregone interest) were not included in the cost estimation, thus the cost estimate given represents only the present value initial cost.

Table 4 – The cost determination structure for the wetland placement model. Costs (NZ$) are broken down by the influencing layer then the classification within that layer and given in New Zealand dollars.

Classification	NLCD #	Modification	Modification Cost (NZ$)	Source
Open Water	11	Final Land Score = 0		Assumption
Low Intensity Residential	21	Demolition	$110.00 /$m^2$	Rawlinsons
Commercial/Industrial/Transportation	23	Demolition	$330.00 /$m^2$	Rawlinsons
Bare Rock/Sand/Clay	31	Top Soil Fill	$17.12 /$m^2$	RS Means*
Quarries/Strip Mines/Gravel Pits	32	Top Soil Fill	$17.12 /$m^2$	RS Means*
Transitional	33	Clearing	$60.00 /$m^2$	Estimate
Deciduous Forest- Native	41	Preservation	$0.00 /$m^2$	Assumption
Deciduous Forest- Exotic	41	Clearing	$100.00 /$m^2$	Rawlinsons
Evergreen Forest- Native	42	Preservation	$0.00 /$m^2$	Assumption
Evergreen Forest- Exotic	42	Clearing	$100.00 /$m^2$	Rawlinsons
Mixed Forest- Native	43	Preservation	$0.00 /$m^2$	Assumption
Mixed Forest- Exotic	43	Clearing	$100.00 /$m^2$	Rawlinsons
Shrubland- Native	51	Preservation	$0.00 /$m^2$	Assumption
Shrubland- Exotic	51	Clearing	$60.00 /$m^2$	Estimate
Orchards/Vineyards/Other	61	Clearing	$60.00 /$m^2$	Rawlinsons
Grassland/Herbaceous- Native	71	Preservation	$0.00 /$m^2$	Assumption
Grassland/Herbaceous- Exotic	71	Clearing	$40.00 /$m^2$	Estimate
Pasture/Hay	81	Preservation	$0.00 /$m^2$	Assumption
Row Crops	82	Clearing	$0.00 /$m^2$	Estimate
Emergent Herbaceous Wetlands- Native	92	Preservation	$0.00 /$m^2$	Assumption
Emergent Herbaceous Wetlands- Exotic	92	Preservation	$0.00 /$m^2$	Assumption
Habitat Establishment Cost	-	-	$65.00 /$m^2$	Estimate

*Using an exchange rate of .78 New Zealand Dollars to 1 United States Dollar

2.7 Land Score Computation

Suitability of sites for CWs will be based on a combination of traditional cost-benefit analysis and Mauri Model analysis. The final land score (S) was based on the following formula:

$$S = \begin{cases} 0 & M \le 0 \text{ or } \psi < x \\ \dfrac{k_1\psi + k_2 M + k_3 R}{C} & M > 0 \end{cases} \qquad (3)$$

Where ψ is the pollutant accumulation factor; M is the Mauri Model score; R is the riparian function score; k_1, k_2, and k_3 are weighting constants; and C is the cost. M scores below zero represent negative cultural improvement and are assigned values of 0. The assessment of benefits was based on the weighted average approach used by Palmeri and Trepel[62] and Mollot and Bilby[63]. By combining several different buffer models with different priorities, sites are identified that achieve multiple goals simultaneously[1].

The weighting constants k_1, k_2 and k_3 were found using the following equations:

$$k_1 = \frac{C_{min}}{\psi_{max}} \quad (4) \qquad k_2 = \frac{C_{min}}{M_{max}} \quad (5) \qquad k_3 = \frac{C_{min}}{R_{max}} \quad .(6)$$

Where C_{min} is minimum cost per square meter, ψ_{max} is the maximum pollutant accumulation factor, M_{max} is the maximum mauri model score, R_{max} is the maximum riparian function score. Equations 4-6 effectively normalizes the pollutant accumulation factor, the Mauri Model score and the riparian function score to cost thus weighting each factor evenly. These weighting factors can be further adjusted on a per project basis to reflect the priorities of the project.

3. Results & Discussion

The model presented above uses several small components that each evaluate a portion of the effect that restoration or preservation of a parcel would have. Each of these components was evaluated across the Tarawera Watershed and the results are described below.

3.1 Model Assessment

The pollutant accumulation factor, shown in Figure 1, mapped areas of likely pollutant contamination. In order to directly verify the results of the pollutant accumulation factor, one would have to perform an extensive analysis of contaminant sources throughout the watershed that includes not only hundreds of sample points, but repeated multi-temporal sampling. Rather than testing for a full range of contaminants, biotic indicators could be used to assess how potent the pollutants at a particular site are. However, such an extensive study is beyond the scope of this paper. Rather, the effectiveness of the pollutant accumulation factor will be assessed qualitatively.

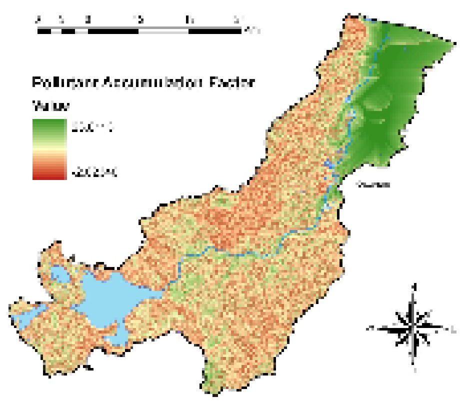

Figure 1 – The pollutant accumulation factor computed across the Terawera Watershed.

Most of the viable areas identified by the model were located either in the northeastern coastal low-lands or in the valleys of the upper watershed. The valleys were prioritized because of the large area that drains into these areas. The lowlands conversely, were scored highly because their slope is extremely low. This result is sensible given that these areas were historically wetlands and that the pollutant accumulation factor was devised from the wetness factor, an indicator of wetland presence. While wetlands are highly valuable ecosystems, it is not likely that significant quantities of pollutants would reach all of the lowland areas identified, therefore negating their value in terms of pollutant removal. Thus, it seems that low slope is overvalued in the pollutant accumulation factor and that future modification of the model should reduce the influence of slope.

The final Mauri Model score is provided in Figure 2. One will notice that the lowland areas received rather low scores except for patches in the middle where historical flooding has taken place. The riparian function score for the Tarawera Watershed is shown in Figure 3. The lowland areas that were historically wetlands have smaller buffers surrounding the streams since these areas contribute less to temperature regulation and large woody debris.

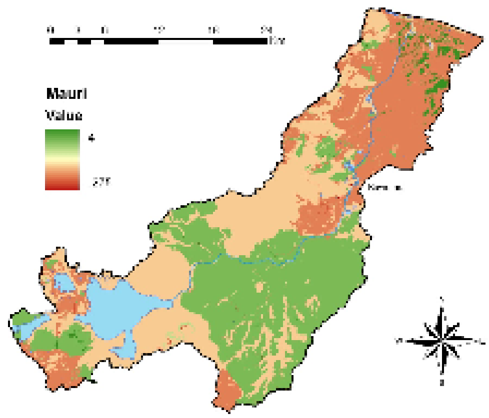

Figure 2 – The overall Mauri Model assessment for the Tarawera Watershed.

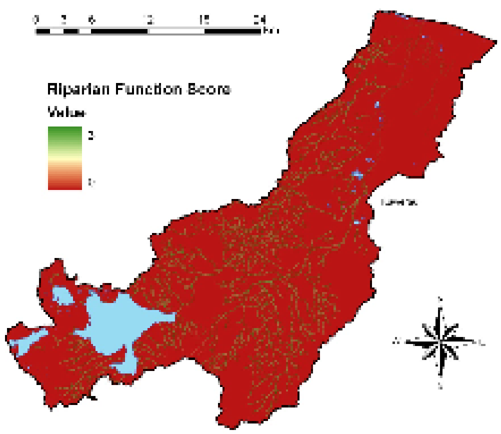

Figure 3 The riparian function score computed for the Tarawera Watershed.

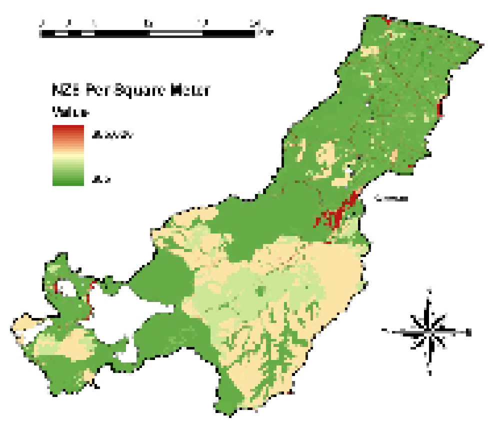

Figure 4 – The initial cost (NZ$) of restoration and preservation per m^2

Figure 4 shows the initial cost per square meter for habitat restoration of a particular parcel. This cost includes the initial cost of purchasing land, the cost of clearing that land if necessary and the cost of planting that area. It does not account for future maintenance costs or the possibility of leasing the land. As is expected, developed areas are the most expensive with costs up to \$65,600/m^2 to restore while the low lying areas and the highlands around lake Tarawera are the least costly with costs as low as \$65/m^2. The areas in the middle of the watershed are mostly land used for logging of exotic *Pinus radiata* and have an intermediate cost with respect to other areas of the watershed.

3.2 Habitat Restoration Suitability Score

The final score was computed for the Tarawera Watershed from each of the layers discussed above and is given in Figure 5. One will notice that the low lying, northeastern areas of the watershed have some of the highest scores especially the large areas that have been historically impacted by floods. As noted in Section 3.1 the scores in this area may be somewhat inflated because of the high pollutant accumulation factor that results from the prioritization of low slope areas. The remainder of the watershed has concentrated areas surrounding the stream network where restoration and preservation should occur. This is interesting because only the riparian function score is linked to the stream network, as to account for specific effects that riparian restoration has on stream function. Thus, even thought this model is not specifically aimed at identifying riparian restoration zones, it identifies these areas as strong candidates for restoration.

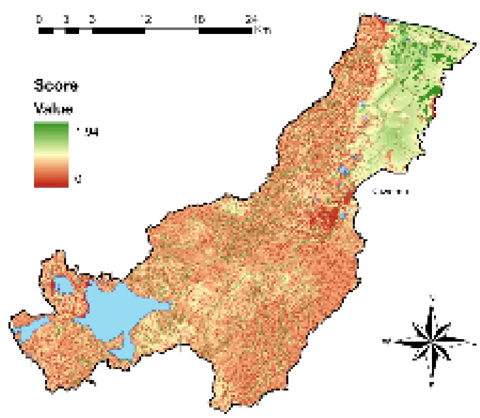

Figure 5 – The restoration suitability score for the Tarawera Watershed

3.3 Error

Because of the extent of parameters involved in this buffer placement model, it is expected that error is not negligible. To further compound error within the model, there is imprecision in the geographic locations of up to ±10m. Finally, layers such as soil type define hard boundaries between values when in fact there is a continuous gradient between these values. A detailed quantitative assessment of error within this model is beyond the scope of this project, but would be worthwhile for future study.

3.4 General Applicability

This model makes use of readily available data in a simple format that can be understood and applied by those with a non-technical background. While precise modeling cannot be achieved with this approach, significant information relevant to decision making can be gleaned. Once a site has been identified using this model, it than can undergo a more rigorous suitability assessment.

In general the methods devised here are easily transferable to other watersheds. Although the Mauri Model was developed with Māori culture in mind, many other indigenous cultures share similar views (Morgan, 2006). Even beyond indigenous culture, populations of all nations can appreciate and the four well-beings of the Mauri Model, but the weighting between them may be different. Still, the Mauri Model has the distinct advantage of being able to evaluate parameters possessing intrinsic value rather than monetary value making it an essential part of any watershed assessment.

The rubrics used for calculating the pollutant accumulation factor, the riparian function score and the cost will certainly need to be adjusted based on geographic location. However, this adjustment should be straightforward. Areas where groundwater flow is significant hierologically will require more extensive alterations to the model such to account for the flow of pollutants underground. This is an topic for further research.

4. Conclusion

Future work is needed to assess the error associated with the model. Also, revision of the pollutant accumulation factor is needed such that extremely low slope areas are not given over-inflated scores. Finally, future research should develop methods to account for groundwater flow throughout the watershed as this can be a significant means of pollutant transport.

This project has developed a viable means for siting CWs within a large-scale watershed. The output of the model is a set of potential wetland sites that are desirable based on pollutant removal capability, riparian restoration benefits, cultural consideration and economics. The method is simple enough to be applied by land planners with limited technical background and makes use of readily available data.

5. Acknowledgements

Arthur Kney, Dietrich Hoefner, Environment Bay of Plenty, Frontiers Abroad, Glenn Ellery, Janine Barbor, Joshua Blackstock, Kepa Morgan, The Lafayette College Society of Environmental Engineers and Scientists (SEES), Michele Hosking. Funded in part by a EPA Greater Research Opportunities Fellowship.

6. References

1 G. Bentrup and T. Kellerman, "Where should buffers go? Modeling riparian habitat connectivity in Northeast Kansas," *Journal of Soil and Water Conservation* 59, no. 5 (2004): 209.

2 J. A. Kusler and M. E. Kentula, *Wetland creation and restoration: the status of the science.* (Washington, D.C.: Island Press 1990), xvii-xxv.

3 M. E. Kentula, R. P. Brooks, S. E. Gwin, C. C. Holland, A. D. Sherman, J. C. Sifneos, An approach to improving decision making in wetland restoration and creation. (Washington, D.C.: Island Press, 1992).

4 A. B. Cooper, "Nitrate depletion in the riparian zone and stream channel of a small headwater catchment," *Hydrobiologia* 202 (1990): 13-26.

5 K. J. Collier, A. B. Cooper, R. J. Davies-Colley, J. C. Rutherford, C. M. Smith, R. B. Williamson, *Managing riparian zones: a contribution to protecting New Zealand's rivers and streams, volume 2: guidelines.* (Wellington: Department of Conservation, 1995).

6 R. Lowrance, R. Todd, J. Fail Jr., O. Hendrickson Jr., R. Leonard, L. Asmussen, "Riparian forests as nutrient filters in agricultural watersheds," *BioScience* 34 (1984): 374-377.

7 A. D. Muscott, G. L. Harris, S. W. Bailey, D. B. Davies, "Buffer Zones to improve water quality: A review of their potential use in United Kingdom agriculture," *Agriculture, Ecosystems and Environment* 45 (1993): 59-77.

8 R. B. Williamson, C. M. Smith, A. B. Cooper, "Watershed riparian management and its benefits to a eutrophic lake," *Journal of Water Resources Planning and Management* 1 (1996): 24-32.

9 E. J. Hickin, "Vegetation and river channel dynamics," *Canadian Geographer* 28 (1984): 111-127.

10 K. Lee, T. M. Isenhart, R. C. Schultz, S. K. Mickelson, "Multispecies riparian buffers trap sediment and nutrients during rainfall simulations," *Journal of Environmental Quality* 29 (2000): 1200-1205.

11 F. D. Shields, A. J. Bowie Jr., C. M. Cooper, "Control of streambank erosion due to bed degradation with vegetation and structure." *Water Resources Bulletin* 31 (1995): 475-489.

12 U. Tim, S. R. Jolly, H. H. Liao, "Impact of landscape feature placement on agricultural non-point source-pollution control." *Journal of Water Resources Planning and Management* 121 (1995): 463-470.

13 J. L. Probst, "Nitrogen and phosphorus exportation in Garonne Basin (France)," *Journal of Hydrology* 76 (1985): 281-305.

14 A. N. Sharpley, S. J. Smith, "Phosphorus transport in agricultural runoff: the role of soil erosion" in *Soil Erosion on Agricultural Land,* eds. J. Boardman, I. D. L. Foste, J. A. Dearing (London: Wiley, 1990), 351-365.

15 J. W. Thomas, C. Maser, J. E. Rodiek, "Riparian zones" in *Wildlife Habitats in Managed Forests,* ed. J. W. Thomas, (U.S. Department of Agriculture Forest Service Handbook No. 553., 1979).

16 R. J. Naiman, H. Decamps, M. Pollock, "The role of riparian corridors in maintaining regional biodiversity," *Ecological Applications* 3 (1993): 209-212.

17 C. Maisonneuve, S. Rioux, "Importance of riparian habitats for small mammal and heptofaunal communities in agricultural landscapes of southern Quebec," *Agriculture, Ecosystems, and Environment* 83 (2001): 165-175.

18 J. S. Hanson, G. P. Malanson, M. P. Armstrong, "Landscape fragmentation and dispersal in a model of riparian forest dynamics," *Ecological Modeling* 49 (1990): 277-296.

19 C. S.Machtans, M. A. Villard, S. J. Hannon, "Use of riparian buffer strips as movement corridors by forest birds" Conservation Biology 10 (1996): 1366-1379.

20 F. T. Burbrink, C. A. Phillips, E. J. Heske, "A riparian zone in southern Illinois as a potential dispersal corridor for reptiles and amphibians." *Biological Conservation* 86 (1998): 107-115.

21 R. E. Bilby, J. W. Ward, "Changes in characteristics and function of woody debris with increasing size of streams in western Washington," *Transactions of the American Fisheries Society* 118 (1989): 368-378.

22 M. E. Harmon, J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, et al., "Ecology of coarse woody debris in temperate ecosystems," *Advances in Ecological Research* 15 (1986): 133-302.

23 C. Chu, N. E. Jones, L. Allin, "Streams in the Great Lakes Basin, Ontario, two landscape and climate variables." *River Research and Applications* 26, no. 3 (2010): 221-241.

24 D. R. DeWalle, "Modeling Stream Shade: Riparian Buffer Height and Density as Important as Buffer Width." *Journal of the American Water Resources Association* 46, no. 2 (2010): 323-333.

25 J. M. Quinn, G. F. Crocker, B. J. Smith, M. A. Bellingham, "Integrated catchment management effects on flow, habitat, instream vegetation and macroinvertebrates in Waikato, New Zealand, hill-country streams," *New Zealand Journal of Marine and Freshwater Research* 43, no. 3 (2009): 775-802.

26 T. R. Roth, M. C. Westhoff, H. Huwald, J. A. Huff, J. F. Rubin, G. Barrenetxea, et al., "Stream temperature response to three riparian vegetation scenarios by use of a distributed temperature validated model," *Environmental Science & Technology* 44, no. 6 (2010): 2072-2078.

27 R. H. Kadlec, S. D. Wallace, *Treatment wetlands, second edition.* (Boca Raton: CRC Press, 2009)

28 I. J. Schlosser, "Stream fish ecology: a landscape perspective," *BioScience.* 41, no. 10 (1991): 704-712.

29 J. B. Kauffman, R. L. Beschta, N. Otting, D. Lytjen, "An ecological perspective of riparian and stream restoration in the Western United States," *Fisheries.* 22, no. 5 (1997): 12-24.

30 W. G. Crumpton, "Using wetlands for water quality improvement; the importance of a watershed scale approach," Water Science and Technology 44, no. 11-12 (2001): 559-564.

31 J. B. Hyman, S. G. Leibowitz, "A general framework for prioritizing land units for ecological protection and restoration," *Environmental Management* 25, no. 1 (2001): 23-35.

32 W. J. Mitsch, J. W. Day Jr., "Restoration of wetlands in the Mississippi-Ohio-Missouri (MOM) River Basin: Experience and needed research," *Ecological Engineering* 26, no. 1 (2006): 55-69.

33 W. Xiang, "Application of a GIS-based stream buffer generation model to environmental policy evaluation," *Environmental Management* 17, no. 6 (1993): 817-827.

34 J. D. Phillips, *Evaluating estuarine shoreline buffer zones for nonpoint source pollution control, in Coastal Zone '89,* (New York: American Society of Agricultural Engineers, New York, 1989), 399-411.

35 M. G. Dosskey, "Assessment of concentrated flow through riparian buffers," *Journal of Soil and Water Conservation* 57, no. 6 (2002): 336.

36 L. J. Bren, "The geometry of a constant buffer-loading design method for humid watersheds," Forest Ecology and Management 110, no. 1-3 (1998): 113-125.

37 G. Vellidis, M. C. Smith, S. G. Leibowitz, W. B. Ainslie, B. A. Pruitt, "Prioritizing wetland restoration for sediment yield reduction: a conceptual model." *Environmental Management.* 31, no. 2 (2003): 301-312.

38 T.K.K.B Morgan, "Decision-support tools and the indigenous paradigm," *Engineering Sustainability* 159, no. ES4 (2006): 169-177.

39 D. Hoefner, Unpublished, (2009).

40 A. Bruere, "Pulp and Paper Mills in the Bay of Plenty," *Environment Bay of Plenty Environmental Publication*. (2003)

41 K. Tull, " "Mini-superfund" site in Kawerau, New Zealand: A closer look at water quality," Masters Thesis, Duke University (2008).

42 Sinclair Knight Mertz Inc., "Tasman primary solids waste landfill: hydrogeological investigation. Rep. Vol. 1." (Auckland: Sinclair Knight Mertz Inc., 2007)

43 M. Marsden, "Kaitiakitanga: A definitive introduction to the holistic world view of the Māori," 2010, www.marinenz.org.nz/documents/Marsden_1992_Kaitiakitanga.pdf.

44 I. D. Moore, R. B. Grayson, A. R. Ladson, "Digital terrain modelling: a review of hydrological, geomorphological and biological applications," *Hydrological Processes* 5 (1991) 3-30.

45 K. J. Beven, M. J. Kirkby, "A physically based, variable contributing area model of basin hydrology," *Hydrological Science Bulletin.* 24, no. 1-3 (1979): 43-69.

46 A. Rodhe, J. Seibert, "Wetland occurrence in relation to topography: a test of topographic indices as moisture indicators," *Agricultural and Forest Meteorology* 98 (1999): 325-340

47 P. Merot, H. Squividant, P. Aurousseau, M. Hefting, T. Burt, V. Maitre, M. Kruk, A. Butturini, C. Thenail, V. Viaud, "Testing a climato-topographic index for predicting wetlands distribution along an European climate gradient," *Ecological Modeling* 163, no. 1-2 (2003): 51-71.

48 I. D. Moore, T. W. Norton, J. E. Williams, "Modeling environmental heterogeneity in forested landscapes," *Journal of Hydrology* 150 (1993): 717-747.

49 M. P. O'Neill, J. C. Schmidt., J. P. Dobrowolski, C. P. Hawkins, C. M. U. Neale, "Identifying sites for riparian wetland restoration: Application of a model to the Upper Arkansas River Basin," *Restoration Ecology* 5, no. 4 (1997): 85-102.

50 G. D. Russell, C. P. Hawkins, M. P. O'Neill, "The role of GIS in selecting sites for riparian restoration based on watershed hydrology and land use," *Restoration Ecology* 5, no. 4S (1997): 56-68.

51 Z. Qiu, "Assessing critical source areas in watersheds for conservation buffer planning and riparian restoration," *Environmental Management* 44 (2009): 968-980.

52 M. G. Anderson, C. E. Ferree, A. P. Olivero, F. Zhao, "Assessing floodplain forests: Using flow modeling and remote sensing to determine the best places for conservation," Natural Areas Journal 20, no. 1 (2010): 39-52.

53 M. D. Tomer, D. E. James, T. M. Isenhart, "Optimizing the placement of riparian practices in a watershed using terrain analysis," *Journal of Soil and Water Conservation* 58, no. 4 (2003): 198-206.

54 L. Heathwaite, P. F. Quinn, C. Hewett, "Modelling and managing critical source areas of diffuse pollution from agricultural land using flow connectivity simulation," *Journal of Hydrology* 304, no. 1-4 (2005): 446-461.

55 S. K. Jenson, J. O. Domingue, "Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis," *Photogrammetric Engineering and Remote Sensing* 54, no. 11 (1988): 1593-1600.

56 M. O. Ribaudo, R. D. Horan, M. E. Smith, "Economics of water quality protection from nonpoint sources: theory and practices," *Agricultural economics report no. 782*, (Resource Economics Division, Economic Research Service, U.S. Department of Agriculture, 1999): 106.

57 M. L. Murphy, K. Koski, "Input and depletion of woody debris in Alaska streams and implications for streamside management," *North American Journal of Fisheries Management* 9 (1989): 427-436.

58 M. H. McDade, F. J. Swanson, W. A. McKee, J. F. Franklin, J. Van Sickle, "Source distances for coarse woody debris entering small streams in western Oregon and Washington," *Canadian Journal of Forestry Research* 20 (1990): 326-330.

59 Rawlinsons, *Rawlinsons New Zealand Construction Handbook*, *24th ed.* (Auckland: Rawlinsons Media Limited, 2009)

60 E. A. Frimpong, J. G. Lee, A. L. Ross-Davis, "Floodplain influence on cost of riparian buffers and implications for conservation programs," *Journal of Soil and Water Conservation,* 62, no. 1 (2007): 33.

61 A. Wossink, D. Osmond, "Cost and benefits of best management practices to control nitrogen in the upper and middle coastal plain," (North Carolina Cooperative Extension, AG-621, 2001).

62 L. Palmeri, M. Trepel, "A GIS-based score system for siting and sizing of created or restored wetlands: two case studies.," *Water Resources Management* 16 (2002): 307-328.

63 L. A. Mollot, R. E. Bilby, "The use of geographic information systems, remote sensing, and suitability modeling to identify conifer restoration sites with high biological potential for anadromous fish at the Cedar River Municipal Watershed in Western Washington, USA," *Restoration Ecology* 16, no. 2 (2008): 336-347.