Spatial Patterns in Land Use and Water Quality in the Tillamook Bay Watershed: A GIS Mapping Project

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Executive Summary:

Degradation of water quality is important to the residents and visitors of Tillamook Bay because it has been linked to loss of income due to oyster bed closures, declines in salmonid populations and can result in a decrease of recreational use of the estuary's resources. Both point and non-point sources of pollution have been targeted for investigation by the Tillamook Bay National Estuary Project (TBNEP), a project designed to bring local stakeholders and citizens together with State and Federal regulators and scientists.

The process undertaken by all estuary projects admitted into the National Estuary Program follows the sequence: establishment of key environmental problems, gathering of available information pertaining to these key problems, and development of a conceptual framework that can be used to identify data gaps and guide scientific research efforts. The ultimate outcome of all National Estuary Projects is to develop a science-based, Comprehensive Conservation Management Plan. To this end, TBNEP has developed a geographic information system (GIS) to organize, analyze and archive data collected and generated during this four year project. Presently, more than 120 separate GIS data layers have been archived within the TBNEP GIS, yet few studies have been completed that use the tremendous analytical power of GIS. Therefore, this study was commissioned to demonstrate how existing data could be used to address a TBNEP priority problem: contamination of the waters of Tillamook Bay by water-borne pathogens as indicated by fecal coliform bacteria.

Patterns in land use and water quality were explored using 12 existing layers from the TBNEP GIS. One new data layer (1:24,000 DEM) was acquired for this research and 13 new data layers generated during the course of the modeling. The first part of this report characterizes portions of the Tillamook Bay watershed as it relates to dairy herd densities by subbasin. The modeled results showed dairy herd densities to range from 0.52 cows acre^{-1} within a subbasin of the Kilchis River to 33.86 cows acre^{-1} within a subbasin of the Miami River. Also in this report, STORET water quality monitoring data were summarized using GIS. This exercise demonstrated that it was difficult to actually get the data from DEQ to analyze and that the paucity of data dramatically limited the scope of analysis such that even a simple trend analysis of the yearly averages of selected variables was difficult to interpret. Finally, this report presents a prescriptive mapping scenario to demonstrate how GIS can be used by resource managers to examine probable outcomes of management actions using computer models.

This work demonstrates how science can be linked with adaptive management. First, existing data were examined and spatial analysis performed. Second, results were presented in several ways along with study assumptions and limitations and various management alternatives were presented. Finally, studies were suggested to fulfill data needs so that better prescriptions can be developed in future iterations. In this way, managers know what scientists need to refine

management alternatives and resource managers know the limitations imposed upon study results by inadequate or poor quality data.

Introduction:

The quality of the aquatic and marine resources is important to the citizens of Tillamook County and to the visitors who come to vacation at the Oregon Coast. The quality of the water determines if shellfish growers can harvest and market their oysters, if water bodies can be used for contact recreation like SCUBA diving or swimming, and if recreational clam harvesters will become ill from eating clams or from coming into contact with water-borne pathogens. Perhaps more subtle, are the effects that poor water quality has on other organisms that live in the waters of Tillamook Bay. Salmon, Dungeness crab, sturgeon, herring, eelgrass, shrimp, bald eagles, and a diversity of waterfowl all depend on clean water.

In 1992, Tillamook Bay was nominated to the National Estuary Program by Oregon's Governor on behalf of the people of Oregon. Contamination of water by pathogenic bacteria and viruses was identified in this Nomination Package as a priority problem affecting both agricultural and commercial shellfishing industries of the Tillamook Bay community. However, data and information necessary to assess the magnitude of water quality problems and to begin to address their causes were scant. The Oregon Department of Environmental Quality (DEQ) is the agency that is primarily responsible for determining the quality of water in Oregon.

The goal of all National Estuary Projects is to develop a Comprehensive Conservation Management Plan (CCMP). In order to develop a science-based CCMP, most estuary projects within the National Estuary Program are required to produce a Scientific-Technical Characterization Report from existing data and information. These exercises can help resource managers to identify data gaps and may sometimes reveal hidden links between ecosystem components. In addition, information presented in characterization reports can also serve to establish quantitative benchmarks against which the outcome of management actions can be evaluated.

An initial step in the scientific-technical characterization process is to define the problem by identifying key components and processes and establishing a baseline condition. In the case of water quality in Tillamook Bay, a conceptual model describing various components and their interactions was developed from information presented during the TBNEP Water Quality Issue Forum (TBNEP, 1995). Figure 1 shows potential sources, sinks and transport pathways for fecal coliform bacteria, a TBNEP priority problem, in the Tillamook Bay watershed.

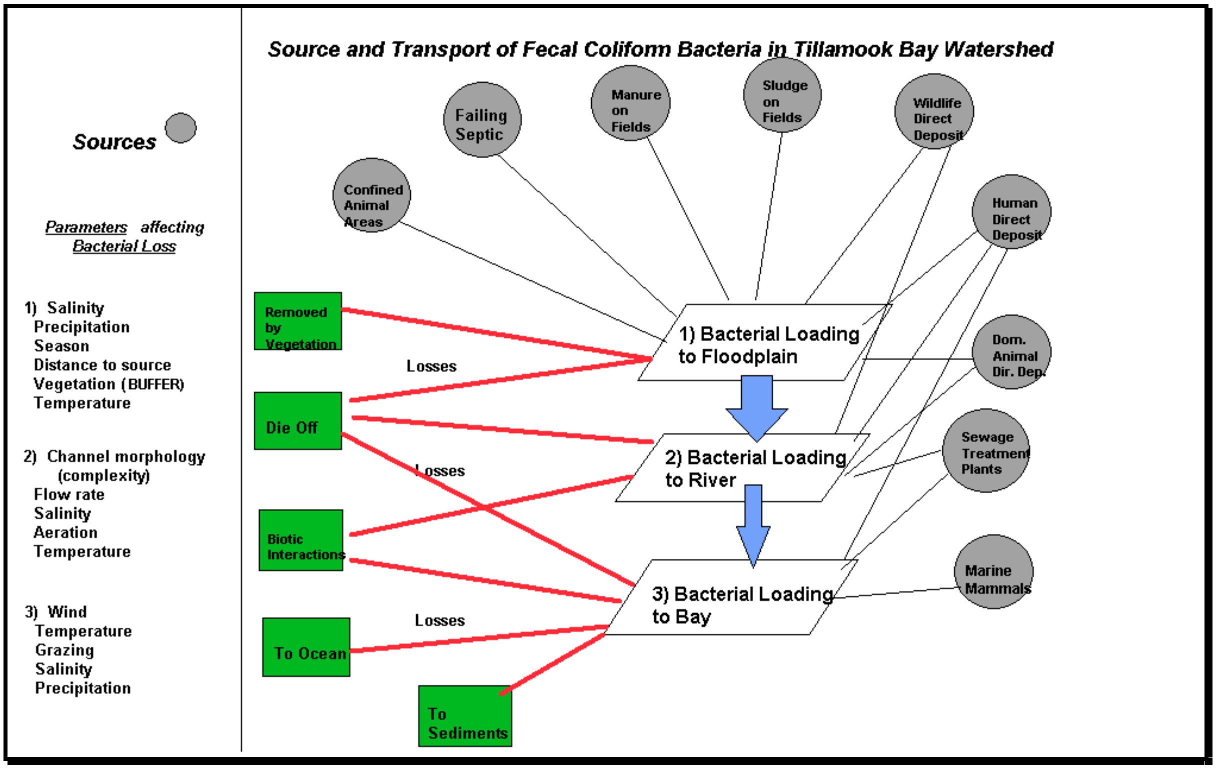

Figure 1. TBNEP's Conceptual Model of Fecal Coliform Bacteria Sources, Sinks and Transport Pathways.

Nine potential sources of fecal coliform bacteria are described in the TBNEP conceptual model. Previous studies have evaluated the importance of each of these sources. For example, Westgarth (1967) and Gray (1971) found that non-point pollution sources entering rivers to be the primary source of fecal coliform bacteria to the bay. Currently, there is not enough information to prioritize the potential fecal coliform sources entering rivers (Figure 1); however, previous studies have addressed failing septic tanks, direct deposits by humans and wildlife, biosolid application, sewage treatment plants and dairy wastes.

Results from a number of previous studies have shown failing septic tanks and direct deposit (human and by wildlife) to be small contributors to the total fecal bacteria loading of Tillamook Bay (Crane and Moore, 1986). The contribution of sludge (biosolid) application to fecal bacteria loading of Tillamook Bay remains unknown; however, in 1986 Musselman reported that bacterial densities in sludge (a mixture of human and dairy waste) generated at the Tillamook Cheese Plant ranged from 93,000 to 24,000,000 colony forming units per 100 mL (determined by MPN method). Clearly, these biosolids are a potentially significant source of pathogens if biosolid material is transported into rivers or to the bay before the pathogens die off. Previous studies also report that correctly operating sewage treatment plants do not normally represent a significant source of water-borne pathogens; however, when plants are not functioning properly or when heavy precipitation hinders proper decontamination, sewage treatment plants can become a significant source of fecal bacteria (Crane and Moore, 1986). In addition, findings from a recent study of patterns in fecal coliform bacteria concentrations in the Trask River suggest that outfall from the

Tillamook sewage treatment plant facility may contribute to bacterial loading to the Trask River following a heavy rain (Alexander and Koretsky, 1996). The relative contribution of fecal bacteria by each of the six sewage treatment plants to the bacteria (and pathogen) loading of Tillamook Bay remains unknown.

A potential source of fecal contamination that has received the most attention are dairy farms. Dairy waste has the highest concentration of fecal coliform bacteria compared to the excrement of other animals (Crane *et al*., 1983). More than 322,500 tons of manure are produced each year by dairy animals on Tillamook farms (Tillamook Rural Clean Water Project, 1991). However, not all dairy manure contributes equally to the bacterial loading of Tillamook Bay. If applied at agronomic (uptake) rates, well away from waterways, under dry conditions, nutrients and fecal pathogens contained in the manure should not enter and degrade the waters of Tillamook Bay. Bacteria and pathogens should die off and nutrients should be taken up by plants. The location of the cows and the conditions under which manure is applied can greatly affect the amount of non-point source pollution that enters the bay. ***It is clear that there is much to learn about the relative importance of each of these fecal bacteria sources and the conditions under which each of these sources may become a problem.***

Previous Tillamook Bay water quality studies have not resulted in a ranked listing of importance of the different potential fecal bacterial sources shown in Figure 1, nor were they intended to. What is clear, is that each of these sources has the potential to become responsible for a large proportion of the total fecal bacterial load to Tillamook Bay. For example, Crane and Moore (1986) found that when sewage treatment plants are operating properly, they do not contribute to the fecal bacterial loading of the bay, but that can change dramatically when plants fail. But sewage treatment plants, and other point water pollution sources, are relatively easy to monitor compared to non-point sources. The dynamics of non-point source contaminants over both space and time are much more difficult to assess and monitor.

Study Objectives:

The purpose of this research project was to demonstrate how readily available information contained in the Tillamook Bay NEP geographic information system (GIS) can be used to examine one non-point pollution source (dairy waste) on water quality in Tillamook Bay. Just as Figure 1 permitted the TBNEP Management Conference to organize information and attempt to prioritize potential sources, maps and models can be constructed from GIS data to describe a problem and to analyze various management prescriptions. In the case of the current study, GIS was used to show the locations and magnitude of the fecal bacteria sources in relation to waterways (evaluated largely as the number and location of animals within the watershed). Fecal coliform bacterial sources and transport pathways were mapped and data from the DEQ STORET database summarized. Finally, a prescriptive mapping exercise aimed at minimizing the impact of dairy cows on water quality was constructed to demonstrate how a simple GIS model can be used to explore modifications in land use practices before actions are taken on the ground. Throughout the study, particular attention was paid to data quality issues as the assembled GIS data layers were used to address a specific problem.

Please note: *This study is intended as a* *<u>demonstration</u>* *of how a GIS analysis can be performed and is based on the best available data. Only one new data file was acquired (1:24,000 elevation data in the form of a digital elevation model) which became available only after the first draft of this report was produced. The 1:250,000 DEM provided by the NEP GIS was the only elevation data available for the first draft of this report. Because of poor quality of this data layer however, we elected to acquire the more accurate 1:24,000 DEM data when it became available and make the necessary changes. All TBNEP GIS layers used and created as a result of this project are listed in Appendix I. Metadata for newly created coverages are provided in Appendix II.*

Using GIS to Address Water Quality in the Tillamook Bay Watershed

The Tillamook Bay watershed (over 400,000 acres) is made up of 9 major drainage basins 7 of which are currently impacted by dairy farming including all 5 major river watersheds. The Wilson and Trask Rivers drain approximately 60% of the land area of the Tillamook Bay Watershed (123,774 acres and 114,0012 acres respectively), followed by the Kilchis (42,486 acres), Tillamook (36,438 acres), and Miami Rivers (23,444 acres). The watershed of each river basin contain smaller subbasins, each subbasin, itself a watershed, drains a river reach. There are 122, river reach subbasins or U.S. Geological Survey 4th order hydrologic units (referred to as subbasins in this report) in the Tillamook Bay watershed. Of the 122 subbasins, 14 contain CAFO permits. The number of subbasins containing CAFO permit holders in any one of the five major river drainage basins ranged from one to six and ranged in area from 665.43 acres to 18,024.03 acres (see Table 1). This region, referred to in this report as the study area, is highlighted in Figure 2. Figure 3 identifies each subbasin in the study area and its ID number: these numbers will be used throughout this report.

Table 1. *Area summaries for subbasins containing CAFO permit holders in the Tillamook Bay watershed.*

Subbasin-id	Major Basin	Acres
1	Miami	1,970
2	Miami	2,871
3	North Bay	665
4	Kilchis	1,831
5	Kilchis	792
6	South Bay	1,971
7	Wilson	6,810
8	Trask	18,024
9	Tillamook	9,765
10	Tillamook	1,931
11	Tillamook	10,497
12	Tillamook	3,806
13	Tillamook	4,058
14	Tillamook	2,782
		67,773

Dairy Cow Herd Densities

The first step in examining the pattern in the abundance of cows in the Tillamook Bay basin is to determine dairy herd densities. Under ideal conditions, one would want to know the position of each cow within the watershed at any time. Clearly, it is not practical to know where each cow is in relation to water at any given instant. For this reason, it is necessary to develop a set of assumptions under which an understanding of the general relationship between cows and water quality can be developed, i.e., a model. The next few paragraphs describe how data existing within the TBNEP GIS were used to develop an understanding of where cows are within the watershed. Several iterations are presented, each describing with increasing accuracy the position of cows in the watershed. We will demonstrate that this increase in model accuracy (better idea of where the cows are in the watershed) can only be developed by having more and higher quality data.

A very easy way to determine the density and position of cows in the watershed would be to simply total the animal numbers from the CAFO permits for each subbasin and assign that total to the area of that subbasin (density = no. cows per subbasin area). But cows are not equally distributed across the landscape of the subbasins, i.e., cows are not normally found in developed (urban) areas or in forests. Dairy farms are irregularly arranged across the regional landscape. So how can we get a more accurate picture of the dairy cow densities, and can GIS help?

Using only available data, we set out to come up with a better understanding of cow herd densities for the Tillamook Bay watershed. The first refinement to determining the number of animals reported on CAFO permits for each subbasin was possible by considering the land cover data created from 1993 Landsat TM (Thematic Mapper) satellite imagery. TM imagery is not the most detailed satellite imagery available commercially, but it does provide a reasonably good data set to map land cover. The TM93LAM file was used from the TBNEP GIS. This raster file was first vectorized, then the cover classes were generalized into 4 categories (developed, agriculture/fields, forest, and water). Of the four cover classes, only agricultural/fields were considered to be suitable “cow habitat.” Overall, approximately 35% of the region examined (the study area) was classified as agriculture/fields - areas suitable for dairy cow grazing, and the distribution of suitable versus unsuitable “cow habitat” varied considerably between the subbasins. For example, many of the subbasins were dominated by young forests (see subbasins #1, #2, #12, #13, and #14 in Table 2). Thus, by combining land cover classes (generated from the 1993 TM satellite imagery) with the maps depicting subbasins, the position of cows in the watershed was better approximated than by using the subbasin maps alone.

Table 2. *Summary of generalized land cover for each subbasin containing CAFO permit holders. Area values are presented in acres.*

Subbasin	Developed	Ag/Fields	Forest	Water	Totals	Dev %	AG %	Forest %	Water%
1	4	200	1766	0	1970	0.19%	10.17%	89.63%	0.00%
2	0	142	2729	0	2871	0.00%	4.94%	95.06%	0.00%
3	1	333	331	0	665	0.23%	50.09%	49.68%	0.00%
4	3	564	1262	2	1831	0.18%	30.77%	68.92%	0.12%
5	7	667	107	11	792	0.89%	**84.15%**	13.54%	1.42%
6	74	1697	166	34	1971	3.75%	**86.09%**	8.41%	1.75%
7	88	2875	3833	14	6810	1.29%	42.22%	56.28%	0.21%
8	639	**9089**	8239	57	18024	3.55%	50.42%	45.71%	0.32%
9	298	3899	5473	95	9765	3.05%	39.93%	56.05%	0.97%
10	2	492	1437	0	1931	0.09%	25.49%	74.42%	0.00%
11	60	2756	7677	4	10497	0.57%	26.26%	73.14%	0.04%
12	11	577	3218	0	3806	0.29%	15.17%	84.54%	0.00%
13	9	320	3689	40	4058	0.23%	7.87%	90.92%	0.98%
14	2	202	2577	1	2782	0.07%	7.26%	92.65%	0.02%
Totals	1198	23813	42504	258	67773				

The Trask River subbasin (#8) clearly contains the most cow habitat as defined from land cover data created from imagery taken in 1993 (See Table 2 and Figure 4). The Trask River subbasin contains over 5,000 more acres of cow habitat than its nearest neighbor, but it does not contain the highest relative percentage of agriculture/fields. That distinction belongs to subbasins #5 and #6.

Are there any other existing GIS data layers that might be added to the land cover information to help refine cow density calculations even more? We encountered two such files - the coarse digital elevation model (DEM) and the existing ownership data layer. To work with the elevation file in the vector domain, we first had to vectorize the ELEV250 file found in the TBNEP GIS. After examining the 1:250,000 DEM, we elected to limit the occurrence of dairy herds to areas below 200 feet in elevation. There is nothing magical about the 200 foot mark other than that this was the distinctive break between lowlands and uplands for this particular landscape. [NOTE: To establish this very general elevation threshold, we did not find it necessary to use the newly acquired, more accurate 1:24,000 DEM data layer.] We are assuming that dairy operations must be close to both milking equipment and suitable grazing land, therefore, the dairy herds will occur almost exclusively at lower elevations. Most of the polygons classified as agriculture/fields from the satellite image interpretation that occurred above 200 feet were usually openings created by forestry operations (clear cuts) and are replanted with tree saplings - not suitable for grazing. So, all land classified as agriculture/fields below 200 feet was considered potential cow habitat, and all land classes above 200 feet (including the agriculture/fields class) were labeled as unsuitable cow habitat (Table 3). By combining existing elevation information with 1993 TM satellite imagery and subbasin maps a more refined approximation of herd density and location was made.

Table 3. *Area above and below 200 feet by subbasin (according to 1:250,000 DEM) used to refine cow habitat modeling and cow density calculations.*

Subbasin	Suitable Below 200 ft	Unsuitable Above 200 ft	Totals
1	366	1604	1970
2	97	2773	2871
3	306	360	665
4	707	1124	1831
5	763	29	792
6	1971	0	1971
7	3523	3287	6810
8	11010	7014	18024
9	7386	2379	9765
10	1642	290	1931
11	2908	7589	10497
12	1707	2100	3806
13	175	3882	4058
14	166	2626	2782
Totals	32727	35046	67773

One final refinement was made by adding existing ownership data (OWNER) to the model. Approximately 83% of the study area was privately owned with 55% of this area (or 45.2% of the total, 30,654 acres) classified as non-industrial. Other ownership categories encountered within the study area included Bureau of Land Management, U.S. Forest Service, State, and miscellaneous (see Table 4 and Table 5 for summaries); however, these ownership categories were unsuitable as cow habitat since dairy herds in Tillamook County are privately owned and occur on private property. Only private, non-industrial ownership was considered suitable for dairy farming in our model. All other land ownership categories superseded the land cover results, meaning that only agriculture/fields encountered on non-industrial private land was considered potential cow habitat. The influence that elevation and ownership modifications made on the land cover data is presented in Figure 5, and the final potential cow habitat map created for this exercise is shown in Figure 6.

Table 4. *Ownership summary for entire study area.*

Ownership	Area (Acres)	Percent
Private Industrial (PI)	25,492	37.60
Private Non-industrial (PNI)	30,654	45.20
State	8,135	12.00
Miscellaneous	1,963	2.90
Bureau of Land Management (BLM)	1,126	1.70
U.S. Forest Service (USFS)	403	0.60
Totals	67,773	100.00

Based on the criteria modeled from the land cover, elevation, and ownership GIS layers, a more sophisticated estimate of potential dairy cow habitat was possible. Using the totals from this GIS derived model, cow densities were calculated for each major drainage basin (Table 6) and for each of the 14 subbasins (Table 7).

Table 5. *Summary of ownership for each subbasin in the CAFO permit study area. Shown are the number of acres and the percentage of the subbasin area occupied by each ownership category (MISC = miscellaneous, PI = private industrial, PNI = private non-industrial, STATE = state, BLM = Bureau of Land Management, and USFS = U.S. Forest Service).*

Sum of Acres	Owner						
Subbasin	**BLM**	**MISC**	**PI**	**PNI**	**STATE**	**USFS**	**Grand Total**
1	---	167.54	410.08	341.23	1031.87	---	1970.02
	0.00%	8.59%	21.02%	17.49%	52.90%	0.00%	100.00%
2	---	---	1506.74	167.36	1196.84	---	2870.95
	0.00%	0.00%	52.48%	5.83%	41.69%	0.00%	100.00%
3	---	---	---	514.57	150.78	---	665.43
	0.00%	0.00%	0.00%	77.34%	22.66%	0.00%	100.00%
4	336.08	---	---	982.60	512.36	---	1831.04
	18.35%	0.00%	0.00%	53.66%	27.98%	0.00%	100.00%
5	---	---	---	790.84	---	---	791.74
	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%
6	---	---	---	1990.98	---	---	1970.97
	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%
7	683.74	452.03	91.19	3716.68	1866.33	---	6809.97
	10.04%	6.64%	1.34%	54.58%	27.41%	0.00%	100.00%
8	106.23	75.28	5650.23	11806.54	385.45	---	18024.03
	0.59%	0.42%	31.35%	65.50%	2.14%	0.00%	100.00%
9	---	---	5207.07	4557.48	---	---	9764.56
	0.00%	0.00%	53.33%	46.67%	0.00%	0.00%	100.00%
10	---	---	969.60	961.83	---	---	1931.44
	0.00%	0.00%	50.20%	49.80%	0.00%	0.00%	100.00%
11	0.05	---	6953.15	3140.45	---	403.33	10496.99
	0.00%	0.00%	66.24%	29.92%	0.00%	3.84%	100.00%
12	---	---	3051.61	754.81	---	---	3806.41
	0.00%	0.00%	80.17%	19.83%	0.00%	0.00%	100.00%
13	---	1267.42	779.98	597.34	1413.05	---	4057.79
	0.00%	31.23%	19.22%	14.72%	34.82%	0.00%	100.00%
14	---	---	872.55	331.49	1577.97	---	2782.01
	0.00%	0.00%	31.36%	11.92%	56.72%	0.00%	100.00%
Grand Total	1126.10	1962.57	25492.21	30654.19	8134.65	403.33	
	1.66%	2.90%	37.61%	45.23%	12.00%	0.60%	100.00%

Table 6. *Summary of cow densities for each major drainage basin containing CAFO permit holders.*

Major Basin	# Subbasins	# Cows	Cow Habitat (AC)	Cow Density
Miami River	2	280	37.66	7.43
North Bay	1	317	222.33	1.43
Kilchis River	2	2008	1098.73	1.83
South Bay	1	1840	1731.07	1.06
Wilson River	1	4305	2064.98	2.08
Trask River	1	16956	7925.80	2.14
Tillamook River	6	6329	4649.76	1.36
Totals	14	32035	17730.33	

Table 7. *Summary of cow densities for each subbasin containing CAFO permit holders.*

Subbasin	Cows	No Cows	Total Acres	% Cow Acres	# Cows	Cow Density	# CAFO Permits	% Permits
1	33.82	1936.19	1970.02	1.72%	150	4.43	1	0.83%
2	3.84	2867.11	2870.95	0.13%	130	33.86	1	0.83%
3	222.33	443.11	665.43	33.41%	317	1.43	2	1.67%
4	426.30	1404.75	1831.04	23.28%	1658	3.89	2	1.67%
5	672.43	119.31	791.74	84.93%	350	0.52	7	5.83%
6	1731.07	239.60	1970.67	87.84%	2008	1.16	5	4.17%
7	2064.98	4744.99	6809.97	30.32%	4305	2.08	13	10.83%
8	7925.80	10098.23	18024.03	43.97%	16956	2.14	55	45.83%
9	2869.19	6895.37	9764.56	29.38%	3825	1.33	20	16.67%
10	370.79	1560.64	1931.43	19.20%	486	1.31	2	1.67%
11	1059.03	9437.96	10496.99	10.09%	1503	1.42	8	6.67%
12	181.40	3625.02	3806.41	4.77%	220	1.21	2	1.67%
13	83.03	3974.76	4057.79	2.05%	120	1.45	1	0.83%
14	86.32	2695.68	2782.01	3.10%	175	2.03	1	0.83%
Totals	17730.32	50042.72	67773.05		32203		120	100.00%

According to the Natural Resource Conservation Service (previously the Soil Conservation Service), cow density limits have been set at 3 adult 1,200 lbs. cows per acre. Most of the major basins as well as their subbasins were calculated to be below this threshold. However, three of the 14 subbasins examined exceeded this target herd density.

Both subbasins in the Miami River watershed exceeded this limit as did one of the two subbasins in the Kilchis River watershed; however, there may be reasonable explanations as to why. CAFO permits are attached to farm residences, not fields. It is therefore possible for the holder of the permit to actually graze the cows at different locations. Some may be in the subbasin where the permit holder resides, but other herds, or portions of herds, may be maintained elsewhere. This obvious shortcoming of the CAFO permit process is joined by another problem in that the permit number does not necessarily reflect the actual numbers of cows on a particular piece of land. **For watershed planning to be effective, better accounting of the number and location of animals is extremely important**. For this exercise, it was assumed that the CAFO permit numbers are accurate and that the cows are maintained in close proximity to the permit holder's location.

Before leaving this topic thinking that there is no serious problem with cow densities in the Tillamook Bay watershed, let's consider the impact that parcel level data has on the analysis. Unfortunately, parcel data was available for only a small portion of the study area (subbasin #5 of the Kilchis River watershed). This data layer was combined with the CAFO permit layer and individual farms identified (see Figure 7). Herd densities were then recalculated based on farm boundary extent in addition to the criteria outlined earlier. Since we do not know that precise number of cows nor do we know if the cows are only grazed on parcels associated with the permit, we are still not able to determine the most accurate herd densities as would be expected with this level of mapping. But we do get much better estimates. The herd density for subbasin #5 before considering parcel data was calculated to be 0.52 animals/acre, but with the parcel data addition, herd density for this subbasin jumped to 10 animals/acre. If this pattern were to hold up over the rest of the study area, actual herd densities may indeed be a serious problem. The modeled cow habitat is the area that could potentially support dairy animals. In reality, the number of these acres that actually contain animals is much lower resulting in higher herd densities than calculated here.

Until cow data are properly collected and the remaining parcel data are made available in GIS format (both very reasonable goals), we will not know the answer to this fundamentally important question, but will instead be forced to make assumptions and generalizations. With just a little effort, it would be possible to have an accurate accounting of the number of dairy animals in the Tillamook Bay watershed and an understanding about where they impact the ecosystem over time, which is equally important. Until this information is clearly understood and monitored, the effect the dairy industry has on the Tillamook Bay ecosystem will simply not be known and prescriptive planning will not be effective.

Summary of Water Quality (STORET) Data:

Two computer database files were obtained from TBNEP. These database files contained STORET data for Oregon DEQ monitoring sites in Tillamook Bay and its tributaries from the period 1960-1993. Oregon DEQ was contacted for STORET information for 1993-1996 (Appendix III), but unfortunately did not receive this information as either legible hard or electronic copy.

The two separate databases were merged and combined into a single database file so that each record was identified by its STORET number and the water quality variables made up the columns.

In addition, date codes were parsed so that data could be summarized by day, month and year. This database was then linked to a GIS coverage of Oregon DEQ monitoring locations.

The database contains 2,858 records, each representing monitoring activities at each of 21 sampling locations (STORET codes). In this database, 35 individual water quality variables were added as columns. Not all of the variables are routinely measured at each monitoring station, i.e., some variables are measured at river locations and not at bay locations.

In order to demonstrate how STORET data can be used to answer questions and identify data gaps, several summary figures were prepared using ARCView and Excel. In this exercise, we calculated: (1) mean annual temperature, (2) mean annual concentrations of total coliform, (3) mean annual concentrations of fecal coliform, (4) mean annual concentrations of dissolved oxygen, (5) mean annual concentrations of total phosphorus, and (6) mean annual concentrations of NH_3+NH_4+NO_2+NO_3. Mean average values for selected water quality variables were calculated for seven regions from STORET data (Table 8 and Figure 8 a-f).

Since one average value is calculated for each region for each year, it should be possible to compare long term trends in the annual average for these water quality variables. What the graphs do show is that there are many data gaps in the STORET database during the past 30 years. These gaps make it impossible to determine the long term trends in fecal coliform bacteria, oxygen and nutrient concentrations, as well as temperature. The second point to be made with these graphs is that there is an enormous amount of variability associated with the annual mean of each of these water quality variables. This means that many more replicated samples and/or a more robust experimental design are necessary if statically significant trends are to be detected. In other words, there is currently no way to determine if best management practices are having a positive impact on Tillamook Bay water quality.

Table 8. *Summary of STORET number by region of Tillamook Bay.*

Region	STORET STATION
Tillamook River	402258, 412149
Trask River	412142
Wilson River	412130
South Bay	412006, 412007, 412008, 412009, 412011, 412012, 412013, 412106, 412153, 412176, 412234
Kilchis River	412125
Miami River	412120
North Bay	412014, 412015, 412178, 412521

Please note: *The intention of this exercise was to demonstrate how existing STORET data can be summarized using GIS. This data summary will help resource managers identify data gaps and examine trends in mean annual temperature and in mean annual concentrations of coliform bacteria, dissolved oxygen, and nutrients. The sporadic nature of collections of this data set and the high degree of variability prevent a more rigorous statistical analysis of these data.*

These data have been added to the TBNEP GIS; therefore, GIS users can now use the query capabilities of ARC View to further interrogate what is known.

Figures 8a and 8b do suggest that mean annual concentrations of total and of fecal coliform bacteria are more commonly greater in Tillamook, Trask and Wilson watersheds than in the bay itself. Annual mean fecal bacteria concentrations on the Miami River also appear to be high. This is in agreement with the cow densities that were calculated through the GIS analysis done in this project. However, for reasons already described statistical comparisons cannot be made from STORET data and these observations simply serve to suggest areas where future monitoring should be done. A water quality study was done by Alexander and Koretsky (1996) on the Trask River; however, the high degree of variability in the fecal bacteria counts "profoundly" effected the outcome of statistical comparisons even though three replicated samples were taken during each visit at each site.

Finally, the great degree of fluctuation from year to year in the annual mean temperature and dissolved oxygen concentrations at all sites suggests that not enough samples are being taken during the year to even calculate an annual mean value (see Appendix IV).

303(d) List

Oregon DEQ measures and reports the condition of water quality to the U.S. Environmental Protection Agency (EPA) every two years. The 1972 Federal Clean Water Act in Section 303(d) mandates that Oregon DEQ submit a 303(d) list "identifying those waters for which existing required pollution controls are not stringent enough to achieve that state's water quality standards" (ODEQ, 1996). Oregon DEQ failed to submit 303(d) lists to EPA in 1994. The current Oregon 303(d) lists, released in July 1996, incorporate both 1994 and 1996 listings.

The current 303(d) lists show that many waters of Tillamook Bay, both freshwater and saltwater, remain too degraded to support many of the beneficial uses defined by Oregon DEQ. Furthermore, due to lack of information, many streams have been placed on "Waters of Potential Concern List" and not on the 303(d) list until supporting data are available (ODEQ, 1996). Therefore, the status of Tillamook Bay's waters may actually be worse than what has been reported.

Stream reaches that fell within the study area that failed water quality standards developed by DEQ appear in Figure 9 and are summarized in Table 9. These reaches failed for three possible reasons: (1) excessive fecal coliform concentrations, (2) high water temperatures, or (3) both excessive fecal coliform and high temperature. The existing road culvert file in the TBNEP GIS was considered, but it was so incomplete that it made it virtually useless for any analysis. Sewage treatment plant outfalls were also mapped, but little is known about their impact on water quality. As previously mentioned, sewage treatment plants are not expected to contribute to the overall loading of water-borne pathogens to Tillamook Bay when they are operating correctly (Crane and Moore, 1986). Findings from a recent study of patterns in fecal coliform bacteria concentrations in the Trask River suggest that outfall from the Tillamook sewage treatment plant facility may contribute to bacterial loading to the Trask River following a heavy rain (Alexander and Koretsky, 1996). There is little information regarding the effectiveness of sewage treatment plants under the range of precipitation events that occur in Tillamook.

Another way to consider the impact that dairy herds have on stream water quality is by modeling potential access to waterways by cows. This was done by combining data from the created potential cow habitat file (COWHABF) with the rivers and streams layer (LRIVER & LSTREAM). Total stream length potentially accessible by cows and length excluded from cows for each subbasin was then tallied and mapped. Results showed that streams within subbasins are potentially exposed to direct cow interactions from 0 to 99% (Table 10). Those areas immediately around the southern portion of Tillamook Bay where 4 of the 5 major rivers meet the ocean were found to be most susceptible.

Table 9. *Summary of stream reaches within the study area that failed DEQ water quality standards. (FC = fecal coliform, TEMP = temperature).*

Name	Watershed Subbasin	Cause	Length (m)
Miami River	Miami River	FC	8877
Kilchis River	Kilchis River	FC	12605.63
Murphy Creek	Kilchis River	FC	4229.53
Dougherty Slough	Trask River	FC	8156.36
Holden Creek	Trask River	FC	7419.5
Hoquarten Slough	Trask River	FC	5243.65
Mill Creek	Trask River	FC	3355.79
Trask River	Trask River	TEMP	17228.99
Killam Creek	Tillamook River	FC	10323.52
Bewley Creek	Tillamook River	FC	4890.48
Mills Creek	Tillamook River	FC	4095.76
Simmons Creek	Tillamook River	FC	1380.79
Tillamook River	Tillamook River	FC	31665.76
Wilson River	Wilson River	TEMP/FC	14272.62
Totals			108033.22

Table 10. *Modeled stream access by dairy animals within the study area.*

Watershed	Cow Access Length	Total Length (m)	Percent Streams Potentially Accessed by Cows
1	1,130.19	15,443.23	7.32%
2	0.00	19,413.87	0.00%
3	3,581.85	5,988.15	59.82%
4	4,516.18	11,664.09	38.72%
5	12,066.66	12,229.89	98.67%
6	24,861.84	26,178.38	94.97%
7	21,715.95	57,300.90	37.90%
8	76,072.69	120,285.98	63.24%
9	43,533.50	83,714.73	52.00%
10	3,810.61	13,178.53	28.92%
11	7,557.38	55,943.68	13.51%
12	3,080.95	24,268.47	12.70%
13	756.280897	23,027.67	3.28%
14	762.932728	16,437.65	4.64%
Totals	203,447.03	485,075.22	41.94%

A Prescriptive Mapping Exercise

As part of this project, we wanted to demonstrate how existing GIS data could be used to model different management scenarios to solve the problems identified for the Tillamook Bay watershed. This is considered a prescriptive mapping exercise since we are considering the outcomes of changing existing conditions in some way. [*In an earlier draft of this report, we conducted the modeling using 1:250,000 scale DEM data (at the time of this project the only digital elevation data available). During the review process, this DEM data was found to be so poor that the intent of the exercise was completely overlooked as the issue of data quality became the topic for debate. New digital elevation data has just been released by the state and we elected to redo portions of this project with the finer scale 1:24,000 DEM. These data more closely fit existing U.S.G.S. 1:24,000 paper quads; however, these maps (many still provisional) would NOT provide the level of detail needed for address some questions (e.g., water diversion projects in the valley): that would require more accurate elevation data. As we clearly pointed out in the statements highlighted below in the earlier draft and wish to emphasize again - this mapping exercise is ONLY a demonstration of how GIS can be used to address complex issues. It is NOT intended to be a recommendation for action. Ideally, any GIS should be available to the public with the data used to discuss alternatives to solving problems. Of course, the better the data, the better the ability to measure and predict more effectively. If nothing else, the problem encountered with the coarse DEM data shows how poor datasets (scale related or otherwise) can lead to wrong conclusions. Ideally, the quality and scale of the data should match the question being asked. In this case (since we only wanted to conduct a simple demonstration using existing NEP data) we did not think it was necessary to run it through that filter.*

Unfortunately that one decision caused a lot of unnecessary misunderstanding. Hopefully by using the new 1:24,000 scale elevation dataset (better but still not perfect), the original intention of the exercise can be considered. Throughout this section of the report, all newly added sentences will be presented in [] and italicized.]

The model building exercise outlined here is NOT ***intended to be our recommendation for improving water quality in this ecosystem, but was created to demonstrate how GIS could be used by resource managers to consider a variety of management options.***

The strength of doing these types of exercises in a computer mapping environment is that it allows all interested parties to consider different management options and to develop an understanding of consequences before any actions are ever taken on the ground. *[GIS mapping exercises should not be viewed as another elitist attempt to impose changes on unsuspecting citizens. GIS should be used as the integration tool everyone has a chance to respond to - that clearly happened in this case. And not everyone has to become a computer operator to have their voice heard. All one needs is to try to stay informed and engage in the process.]*

This particular modeling exercise looks specifically at the interaction of dairy cows and water quality in the Tillamook Bay watershed. Dairy cows degrade water quality most obviously by adding substantial amounts of fecal coliform bacteria to the waterways which can find their way to the shellfish beds in Tillamook Bay, itself. Cows also affect stream banks by physically trampling vegetation resulting in increased sediment loading and the degradation of streamside biological integrity. There is another problem when cow and water mix - cows are frequently killed in flooding in this watershed. The floods of 1996 had a considerable impact on the local dairy operations. Property was damaged or destroyed and hundreds of animals were killed. The planning that follows attempts to address both problems to some degree. The objective of this prescriptive planning exercise, therefore, was to minimize contact between dairy cows and water.

[The first data layer considered was the new digital elevation model (DEM). An elevation slice was performed yielding polygons of 1 meter intervals. Figure 10 highlights the areas most at risk to flooding. Aside from stream channels, the area around the south end of Tillamook Bay is most effected. The areas 1-4 meters above sea level were <u>*arbitrarily*</u> *chosen to give a sense of how the lower elevations were distributed with CAFO permits overlaid on top to show which farmers are most at risk. What are some options? The following is just one option strictly for demonstration purposes.]*

What if we were to exclude cows in particular zones and/or modify how other zones were used. For example, let's say we mandate that there are be no cows in the 1-2 meter elevations range above mean sea level - the risk to cow losses and impact on the natural environment warrants this restriction. *[The 2 meter cutoff is an arbitrary selection just to demonstrate how the GIS could help evaluate a policy decision based on existing knowledge. Upon further investigation, it may be found that the cutoff should be 4 meters, or the way flooding occurs in the region, that only removing animals from direct contact with water is warranted. These questions remained unanswered at this time.]* Let's also say that grazing in areas in the 2-3 meter elevation range are to be restricted to seasonal use only. Cows would be excluded from these areas during the wet season, but could return during the drier months. How would the dairy industry be effected by such action? By using GIS, we could quickly determine which farms and how many animals would be effected by this or any other management prescription. In this case, only 7/120 owners and 4.49% of the cows would be effected by the exclusion zone of 2 meters or below. An additional 8 owners would be effected by the seasonal grazing restrictions, and it would impact just under 10% of the total dairy cows in the Tillamook watershed. Approximately 90% of the owners and about the same percentage of the cows would not be effected at all by this management decision other than possibly helping out impacted dairies (Table 11).

Table 11. *Summary of management action on dairy farming.*

Elevation Range	# Dairy Owners	Percent Dairy Owners	# Cows	Percent Cows
GT 0 - 2 meters	7	5.83	1,438	4.49
2-3 meters	8	6.67	1,820	5.68
GT 3 meters	105	87.50	28,778	89.83
	120	100.00	32,036	100.00

Every effort would be made to return the exclusion zone into natural cover as soon as possible which would provide better salmon rearing habitat and possibly provide wetland water catchments which could capture excess run-off and filter sediments and nutrients.

Now let's add a little more complexity. If we wanted to add a restoration component by planning for the return of native riparian vegetation and eliminating contact of dairy animals altogether, what would it look like and how much area would be involved? To model this component, the rivers and streams data layers (LRIVER and LSTREAM) had to be merged. Before this could be done, LRIVER (a polygon file) had to be generalized to form a line file. A buffer was then performed on joined rivers/streams line file. A 100 meter buffer was applied to the main riverways and a 50 meter buffer for all perennial streams. *[Again, these are arbitrary buffer distances, but we wanted to make them larger than what most previous buffer regulations specify.]* This area was added to a modified elevation layer to take into account the cow exclusion zone of 2 meters or less and land ownership. *[The goal here was to show what part of the modeled potential cow habitat would be effected. We intentionally excluded non-private lands.]* The result was a watershed restoration layer which could then be overlaid with the existing potential cow habitat layer. The mapping results are shown in Figure 11 for the subset of the area most effected. Table 12 summarizes the impact of this plan on potential cow habitat for each subbasin. According to this summary table, the Trask River watershed, South Bay, and part of the Tillamook watershed would theoretically be impacted the most.

Table 12. *Summary of the impact of the modeled watershed restoration plan on potential cow habitat for each subbasin. Columns labeled as "Old" are values based on the final potential cow habitat model. Columns labeled as "New" are values reflecting the change to the "Old" condition after watershed restoration lands are removed from the potential cow habitat pool.*

Subbasin	Cows Old	No Cows Old	Totals	Cows New	No Cows New	Totals	Loss of Cow Habitat
1	34	1936	1970	15	1955	1970	19
2	4	2867	2871	3	2868	2871	1
3	222	443	665	152	513	665	70
4	426	1405	1831	224	1607	1831	202
5	672	119	792	249	542	792	424
6	1731	240	1971	318	1653	1971	1413
7	2065	4745	6810	1310	5500	6810	755
8	7926	10098	18024	5781	12243	18024	2145
9	2869	6895	9765	1550	8214	9765	1319
10	371	1561	1931	244	1687	1931	127
11	1059	9438	10497	890	9607	10497	169
12	181	3625	3806	127	3679	3806	54
13	83	3975	4058	66	3991	4058	17
14	86	2696	2782	76	2706	2696	10
Totals	17730	50043	67773	11007	56766	67773	6723

The modeling steps taken were for demonstration purposes only. We chose the 50 and 100 meter buffers to test just one possible management alternative. Using GIS, it is possible to model the impact of applying narrower or wider buffer strips, different restoration applications according to ownership or stream reach, etc. The combinations are wide open, but this is where the true ecology comes into the process. You can model many things using GIS - the challenge is to model reality and ultimately come up with ecological solutions instead of political ones to the suite of complex questions facing ecosystems where humans are active participants.

Prescriptions like the simple one outlined in this demonstration could be implemented in any number a ways. Policy could be made to provide incentives to landowners for making the necessary changes. Portions of disaster relief dollars could be spent on preventative actions versus just compensation for losses that are likely to just occur again. Some land use changes could be made immediately, others would be phased in over time. Whatever action is taken, having everything in GIS makes the system easier to study and understand over the wide breadth of interests allowing for true adaptive management to operate. Monitoring activities can also be organized that not only help understand natural conditions of this watershed, but also help evaluate what impacts management actions are having on the ecosystem. As we learn more about the functionality of this and other watersheds, management prescriptions can be modified accordingly.

Recommendations:

1. The more detailed digital elevation model (DEM) available from the Oregon GIS Data Service Center should be acquired and added to the TBNEP GIS.
2. Parcel maps for the lowlands should be completed, particularly as it relates to dairy farm operators.
3. CAFO permitting process or some other accounting system should reflect actual numbers and locations of dairy animals.
4. Complete culvert data should be obtained and placed into the TBNEP GIS. Very little can be done with the existing data which is limited to a few major roads.
5. Additional remotely sensed data should be classified targeting riparian areas and wetlands. SPOT would be a likely candidate.
6. Need more extensive and regular water quality monitoring particularly in the subbasins of the Miami, Tillamook and Trask Rivers. A river reach or subbasin strategy is recommended to better link water quality with land use.
7. Desperately need a basin-wide GIS-based hydrologic model in order to understand the dynamics of water movement through the Tillamook Bay watershed.
8. Location and application times of biosolid applications need to be investigated.
9. Design a study that can rank the importance of each of the potential fecal coliform bacteria sources and the conditions under which that source is a problem.

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