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A GIS BASED MODEL TO ASSIST WATERSHED MANAGERS ASSESS NONPOINT SOURCE POLLUTION

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by
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ABSTRACT

A GIS BASED MODEL TO ASSIST WATERSHED MANAGERS ASSESS NONPOINT SOURCE POLLUTION

by Ross A. McClenahan

Pollution from diffuse nonspecific sources known as nonpoint source pollution (NPS) has proven to be challenging to manage and reduce. This work uses the Point Pinos Watershed as a case study to evaluate the utility of a GIS-based model designed to identify NPS pollution using readily available data. The Simple Method is used to create an empirical runoff model using existing land use, precipitation, and water quality data, and incorporating a GIS to calculate NPS pollutant loading for ten water quality indicators. The model was evaluated on its ability to assist the user in meeting six specific EPA requirements. The Simple Method model proved an effective tool for calculating annual pollutant loadings for each land use type. This case study highlighted the critical need for the collection of watershed specific data including land use types, event mean concentrations (EMC), and hourly precipitation data for a watershed.

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This process would not have been possible without the unwavering support of my fiancé Robin Dunkin, my family for believing in me, and my furry family Bodhi, Henry, Sage, Sammy, and Taylor for keeping me company while writing.

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INTRODUCTION

Since the Clean Water Act of 1972, significant steps have been taken to reduce the pollution of rivers and streams, ground water, and coastal waterways. While reduction of pollution from point sources such as industrial plants are relatively easy to identify, measure, and regulate, a far more difficult problem is nonpoint source pollution (NPS). NPS pollution is pollution without a single defined source and includes oils and grease as well as heavy metals and excess nutrients that are suspended by rainfall runoff and eventually carried into various waterbodies. While a number of regulatory bodies are charged with the management of NPS pollution under the Clean Water Act, the basic task of estimating current NPS pollution loads is often difficult and costly. However, one way to significantly reduce the cost of implementing a NPS pollution monitoring program is by using commonly collected information that already exists in the databanks of most city and state agencies. By using existing and readily available data a significant pressure is removed from a watershed manager's budget thereby making it more feasible for agencies of all sizes to participate in monitoring NPS pollution from their area of interest.

NPS pollution enters the environment from diffuse sources that tend to be well distributed over any given landscape. Examples of NPS pollutants include excess fertilizers, insecticides, and herbicides from agricultural fields and maintained grasses, oil and grease from urban runoff and manufacturing, sediment from construction sites, farms, and poorly managed drainage basins, bacteria from livestock and pet waste, and heavy metals from various residential and industrial sources (EPA 1994). As storm water runoff moves across the landscape it picks up and transports these natural and man-made pollutants to the receiving waters downslope.

Since the enactment of the Clean Water Act of 1972 point source polluters have reduced emissions by adhering to more stringent environmental standards as well as submitting to regular testing and monitoring by local, state, and federal regulatory agencies (EPA 1994). In contrast, no single industry or party is responsible for NPS pollution, and thus, NPS pollution is a more challenging management problem. In 1987, Congress added section 319 to the Clean Water Act of 1972 which created a national program aimed at identifying and controlling NPS water pollution (Congress 1987). Section 319 requires states, territories, and tribes address the problem of NPS pollution by identifying and cataloging sources that contribute to NPS pollution within their authority and creating both mandated and non-mandated programs to reduce pollution from those sources. Federal grants were also made available to help agencies fund these programs through an application and awards process. In addition, the federal government later recognized that NPS pollution had potentially greater environmental impact in coastal areas in particular, and additional and more stringent management requirements were set in place by Congress and the EPA for these areas.

In 1993 the Environmental Protection Agency (EPA), under authority of section 6217(g) of the Coastal Zone Act Reauthorization Amendments, created the "Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters" (Congress 1990; EPA 1993). This EPA document detailed appropriate management procedures to control NPS pollution from five sources in the coastal zone: agricultural, forestry, urban areas, marinas and recreational boating, and hydromodification. States and territories with coastal management programs were now required to adopt NPS pollution control measures mirroring the guidelines and methods detailed by the EPA.

Adoption of the new EPA mandated measures to control NPS pollution fell to several regulatory agencies. In California these included the state and regional water boards, county water resource agencies, and city public works departments. Each of these groups is responsible for monitoring its own particular area of drainage. Regionally specific agencies also participate in the process, such as the California Coastal Commission. The California Coastal Commission (CCC) was established by voter initiative in 1972 (Proposition 20) and later made permanent by the legislature through adoption of the California Coastal Act of 1976. The objective of the CCC is to manage various coastal issues including water quality (State of California 1972) .

In addition to the public agencies that monitor and regulate NPS pollution, a number of private organizations are concerned with monitoring and reducing NPS pollution as well. For example, the Monterey Bay Sanctuary Citizen Watershed Monitoring Network organizes volunteers to perform water quality sampling throughout the year. Annual reports are issued that focus on NPS pollutants found in samples taken from waterways and city outflows that drain into the Monterey Bay (Hoover 2005). Reports from these groups also identify areas of concern where samples show large quantities of pollutants, and compare across years to monitor for trends in water quality. Other such organizations include The California Stormwater Quality Association, Bay Protection and Toxic Cleanup Program, and Central Bay Water Quality Monitoring

Group. The water quality data collected by private agencies concerned with monitoring NPS pollutant loads from watersheds are important in helping create an historical record of the pollutant loads from a particular watershed or set of watersheds.

The United States Geological Survey (USGS) defines the term watershed as "the divide separating one drainage basin from another" and defines drainage basin as "a part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water" (Langbein *et al.* 1960). Thus, a watershed is a spatially autonomous area with its own drainage system that flows to a common destination or outflow area. The California State Water Board has divided the state's 101 million acres into nine hydrologic regions consisting of 7035 separate watersheds, with each of the nine regions having its own regional Water Quality Control Board. While each of the nine water quality control boards oversees the cumulative water quality management, individual watersheds are managed by various local, city, and county agencies. The management requirements for these various agencies are outlined by the EPA.

The EPA identifies nine watershed management requirements in their 2005 draft publication of the Handbook for Developing Watershed Plans to Restore and Protect Our Waters (EPA 2005a). The nine requirements can be divided into to two categories: 1) identification, measurement, and monitoring, and 2) policy making and implementation of those policies. This case study will focus on solutions to the identification, estimation, and monitoring of NPS pollution runoff, and therefore policy making decisions and enforcements issues are beyond the scope of this discussion.

The four technical requirements set forth in the EPA's handbook and the two implementation requirements that a watershed manager must address when developing a plan for a selected drainage basin are:

Technical

- Identify causes and sources of NPS pollution
- Determine NPS pollutant load and required reduction
- Track implementation of management measures
- Develop monitoring components

Implementation

- Integrate with existing data sets
- Requires small startup investment for initial implementation

Both spatial and quantitative challenges are associated with monitoring, regulating, and ultimately reducing non-point source pollution. To meet the technical requirements listed above, a watershed manager must rely on a modeling process that can address the complex spatial relationships within a watershed as well as effectively address the challenges of quantifying the necessary input variables for a water quality model. In addition, the modeling process needs to be transparent and easily explained to stakeholders in the watershed (EPA 2005a). The EPA requirements discussed above were used as the selection criteria for the GIS model.

Many potential GIS models exist that may meet above criteria. GIS has gained widespread acceptance as a valuable modeling tool and is capable of performing complex spatial operations with the ability to link with and manage large databases of attribute information. While the EPA's draft Handbook for Developing Watershed Plans to Restore and Protect Our Waters does not endorse one particular model, it does give a limited side by side comparison of 36 computer based models. When considering these 36 models and others that are available, only a few address the majority of the requirements outlined above. Four of the 36 models have the ability to model metals, toxins, and nutrients, the main components of NPS pollution: BASINS (Better Assessment Science Integrating Point & Nonpoint Sources), WARMF (Watershed Analysis Risk Management Framework), LSPC (Loading Simulation Program in C++), and the Simple Method based on the Nationwide Urban Runoff Program model (NURP).

The BASINS model developed for the EPA was designed to support analysis of environmental systems, including pollution and runoff events (EPA 2004). BASINS uses a Windows platform and can be integrated with ArcView 3.3 but not ArcGIS or other GIS packages. The program comes with its own input data limiting user supplied datasets for some of the necessary modeling parameters, thereby making it difficult to customize for a specific watershed (EPA 2004).

WARMF was designed to help watershed managers estimate total mass daily loads (TMDL) for most major pollutants using a GIS based interface (EPA 2005c). The WARMF model, also developed by the EPA, routes pollutants over land and through subsurface mechanisms ultimately focusing on river and stream loading. The WARMF model is therefore difficult to apply towards a single or subset of drainage basins that have no large stream or river network. This model is supplied with databases from NOAA, EPA, and USGS, but limits user-supplied land use, water quality, and impervious datasets making this model difficult to integrate with existing data from local sources (EPA 2005c).

LSPC is a model developed by Tetra Tech, Inc. that allows for full customization of user defined inputs. The model is capable of integrating wet-weather storm flows and NPS pollutant loadings into a GIS based system. The LSPC model is a custom application based on the user's requirements but commands significant time and resource investment for implementation; therefore, this model may be better suited for an agency able to commit significant resources towards that end (EPA 2005b; Tetra Tech 2005).

The Simple Method (Stenstrom *et al.* 1984; Stenstrom *et al.* 1993a; Wong *et al.* 1997) for estimating NPS pollution loading is a GIS based model using local land use, precipitation, and water quality data. The Simple Method can be applied to a single or collection of drainage basins, allows for user supplied datasets, requires relatively few monetary resources to implement, and can be integrated with existing datasets in a GIS or database environment. Using local and readily available data as input, the Simple Method model as laid out by Wong *et al.* (1997) in their analysis of the Santa Monica Bay watershed, will be used in this case study to evaluate the utility of a GIS based model for a manager of a small to medium size watershed charged with monitoring NPS pollution runoff.

The Point Pinos watershed in Monterey, California will be used for the case study. The Point Pinos watershed was selected based on the following characteristics: it contains mixed land uses distributed over the entire area, it is located in an environmentally sensitive coastal habitat making it subject to the EPA's stringent NPS pollution guidelines, and there are sufficient local and readily available data for the area (such as land use and precipitation data). The Point Pinos watershed contains no major rivers and therefore carry-through pollutants are not a major concern. In terms of size and land use characteristics the Point Pinos watershed is also representative of many well populated coastal watersheds in California (for example see Stenstrom *et al.* 1993a).

A case study using the Wong *et al.* (1997) adaptation of the Simple Method to estimate the NPS pollutant loading from runoff events in the Point Pinos watershed will be developed for managers with minimal financial and technical resources and will be adaptable to their particular area of study. This GIS-based model will be evaluated for its ability to assist a watershed manager meet the 6 requirements (see above) set forth by the EPA. Performing the case study will also help identify the limitations and challenges of using the Simple Method model. Existing and readily available data from the state, county, and local agencies will be fed into the model producing site specific results. In addition to the evaluation of a GIS based model, the process of data collection and storage by local agencies for use in NPS pollution management will also be discussed.

METHODS

To estimate the NPS pollutant loading from runoff events in the Point Pinos watershed, a two part model was created. Part I included the creation of an empirical runoff model, known as the Simple Method as laid out by Wong *et al.* (1997) (Stenstrom *et al.* 1993a; Wong *et al.* 1996). The model was assembled using data collected from local agencies and included land use types, local rainfall events, water quality measurements, and drainage patterns to estimate the NPS pollutant loading from the watershed area. The modeling parameters for the Simple Method are detailed in Table 1.

Table 1 – Parameters for the Simple Method model

Land Use
Impervious surface area* (IMP)
Area of each land use type*
Runoff coefficient (RV)

Rainfall
Hourly precipitation data*
Average number of storms per wet season (NSTORM)
Average storm runoff volume (ASV)
Annual average storm runoff volume (AASV)

Water Quality
Event mean concentrations* (EMC)
Coefficient of variation per EMC* (COV)
Mean event runoff concentration (ME)

Model Output
Annual pollutant loading (APL)

*Denotes empirical values obtained from local, county, or state agencies (see text for details)

The second aspect of the model brought the empirical runoff data into a vector-based GIS. The GIS was used to process and display spatial information such as land use and watershed boundaries associated with the Point Pinos watershed (Figure 1).

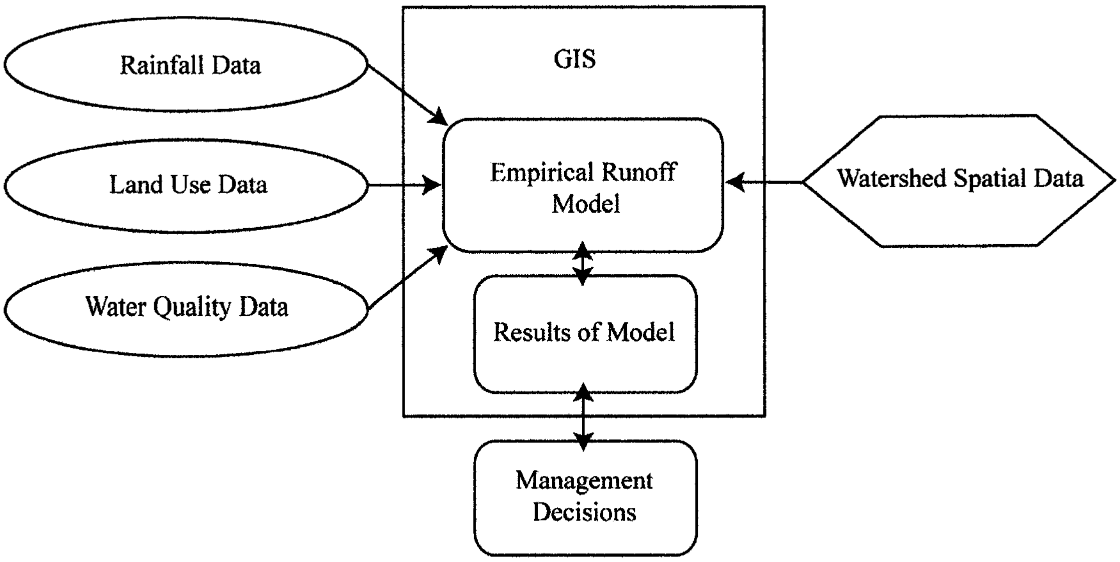

Figure 1: Flow chart depicting the Simple Method GIS model adapted from (Wong *et al.* 1997).

Part I: Empirical Runoff Model

Geographical Area of Study.

This case study was conducted for the Point Pinos watershed (Figure 2; 10,610 acres) located in Monterey County, California, with its spatial characteristics coming from the California Interagency Watershed Map of 1999, as updated in 2004. The California Interagency Watershed dataset serves as the State of California's working definition of watershed boundaries (Figure 2). This GIS dataset is widely used by many public and private agencies including the nine regional water boards and was downloaded from The California Spatial Information Library (State of California 2000).

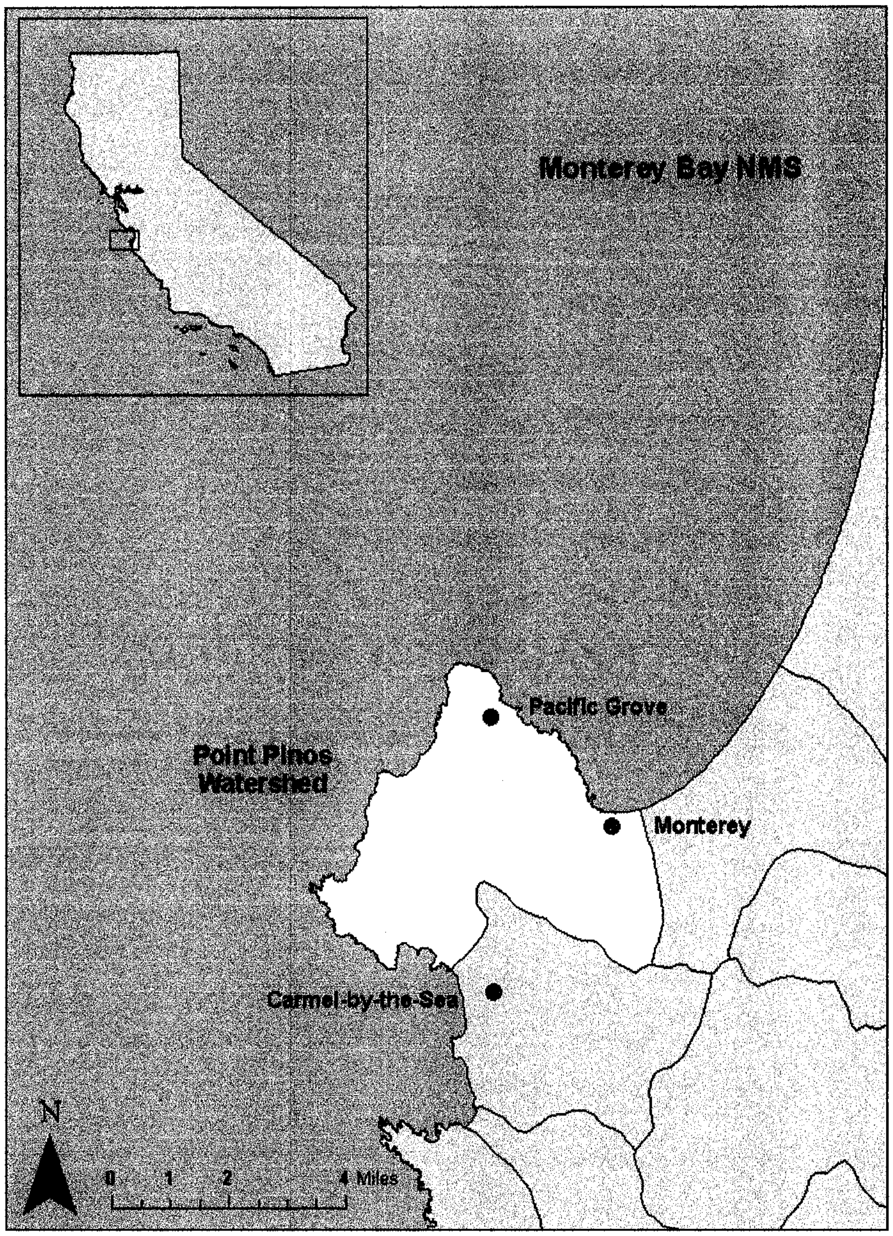

Figure 2: Point Pinos Watershed in Monterey County, California.

Land Use.

The volume of runoff produced by a storm event is directly related to the amount of precipitation and impervious surface area. Impervious surface area is calculated as the percentage of a given area that does not allow water to percolate into the soil (EPA 1992). Generally, land use types combined with corresponding impervious surface values are used to calculate the total impervious surface area for an entire watershed.

Land use data for the Point Pinos watershed was not directly available, so it was derived from an existing readily available Monterey County GIS spatial coverage that included nearly 15,000 parcel polygons and their corresponding Emergency Medical Services tax use code. Based on the 59 unique tax use codes for emergency services, each parcel was assigned to one of eight land use categories, which included single family, multiple family, commercial, public, light industrial, other urban, open, and unknown (Table 2). The Greater Monterey Peninsula Area Plan provided the definition of those eight land use types (Monterey County Board of Supervisors 1994). The spatial file contained 14 tax codes with no associated description so assignments for these were made based on the parcel owner, location, and surrounding land use types (for example see County of Suffolk, NY 2000). The land use categories were designed around a modified level II Anderson classification scheme (Anderson *et al.* 1976) (Table 3). The Anderson classification scheme, a standard technique in land use classification, uses a two-digit code to describe the predominant land use attributes for a given area. This modified Anderson classification scheme was used to describe predominant land use attributes for the Point Pinos watershed.

Table 2 – Tax use codes and assigned land use categories

Tax Use Code	Service Unit Description	Land Use Code
62	No data	Single-family
99	No data	Unknown
1A	Vacant land, 1	Open
1B	Vacant land, 2 or more	Open
1C	One SFD, 1	Single-family
1D	One SFD, 2 or more	Single-family
1E	Two SFD, 1	Single-family
1G	Misc. Improve	Single-family
1H	Two SFD, 2 ore more	Single-family
1M	No data	Open
2A	Vacant	Single-family
2B	Two units, 1	Single-family
2C	Three/Four Units	Single-family
2D	Five/Fifteen Units	Multiple-family
2E	Sixteen/Thirty Units	Multiple-family
2F	Thirty-one Units or more	Multiple-family
2G	Condos	Multiple-family
2J	One SFD Multi-zone	Single-family
3A	Vacant Rural, 1-10 ac.	Open
3B	Vacant Rural, 11-40 ac.	Open
3C	Undevel, 41-300 ac.	Open
3E	Res. Use, Impr. up to 10 a	Open
3G	Rural Mobile Homes	Multiple-family
3H	Nurseries	Commercial
3J	No data	Open
5A	Vacant	Commercial
5B	Comm, shell-type	Commercial
5C	Sub stores	Commercial
5D	Comb store/off/res	Commercial
5E	Office bldg. – 1	Commercial
5F	Office bldg. – multi	Commercial
5G	Med/den office	Commercial
5H	Bank	Commercial

Table 2 cont.

Tax Use Code	Service Unit Description	Land Use Code
5J	Comm/SFD	Commercial
5L	No data	Commercial
5N	Hotel/motel	Commercial
5P	Market	Commercial
5Q	Shop ctr.	Commercial
5R	Serv.stn.	Commercial
5S	Restaurant	Commercial
5T	Theater	Commercial
5U	Auto Sales	Commercial
5V	Misc. bldg	Commercial
5W	Recreation	Open
6B	Light mfg	Light Industrial
6E	Warehouse	Light Industrial
6G	Prod shed	Light Industrial
7A	No data	Public
7C	Frat Organ	Other Urban
7D	No data	Other Urban
7E	No data	Public
7F	Hosp/convos	Commercial
7G	No data	Other Urban
7H	No data	Commercial
8A	No data	Commercial
8B	No data	Commercial
8C	No data	Commercial
8D	No data	Open
Unknown	Unknown	Unknown

*From section 35-60 of the Monterey, CA City Code Table 2

Table 3: Land use and runoff calculations

Land Use Categories	Impervious Surface Area (%)	Runoff Coefficient (RV)
Single Family	42	0.39
Multiple Family	68	0.58
Commercial	92	0.74
Public	80	0.66
Light Industrial	91	0.74
Other Urban	80	0.66
Open	0	0.10
Unknown	65	0.56

Rainfall.

Previous studies such as the EPA's Volume 1 Final Report (EPA 1983) on the NURP study and a report by Driscoll *et al.* (1990) have analyzed large sets of rainfall runoff data over urban and highway areas and have established that the runoff coefficient (RV), defined as the overall average ratio of runoff to rainfall, is highly correlated with impervious surface area (IMP). An exhaustive search of all local, county, and state management agency data sets for impervious surface numbers specific to the Point Pinos watershed was unsuccessful. Therefore, the published IMP values from Wong *et al.* (1997) were used because they were complete and were compiled from areas that are representative of the Point Pinos Watershed in terms of percent land use.

Equation I was used to calculate the runoff coefficient for each land use type. The relationship between RV and IMP is:

I. $$RV = .007\ IMP + 0.1$$

where RV is the runoff coefficient and IMP is impervious surface area in m^2 (Wong *et al.* 1997).

The average annual storm volume (AASV) was then calculated for the Point Pinos watershed based on hourly precipitation data from a five-year period spanning October 2001 through September 2006. The data used were collected from one of two long-term rain gauges the National Weather Service (NWS) operates on the Fort Ord campus. Since the Fort Ord Gauge #1 does not fall directly in the boundaries of the Point Pinos watershed, the 38-year long term average isohyetal map was used to confirm that the gauge accurately represented precipitation values for the watershed (Figure 3). The rain gauge data are readily available from the NWS website and the 38-year long term average isohyetal data are available from the California Spatial Information Library (State of California 2000). Hourly records were manually analyzed to identify separate storm events. Events separated by six or more dry hours were considered separate storms and events that produced less that 0.10 inches of total precipitation were disregarded since these do not produce significant runoff (Stenstrom *et al.* 1993b).

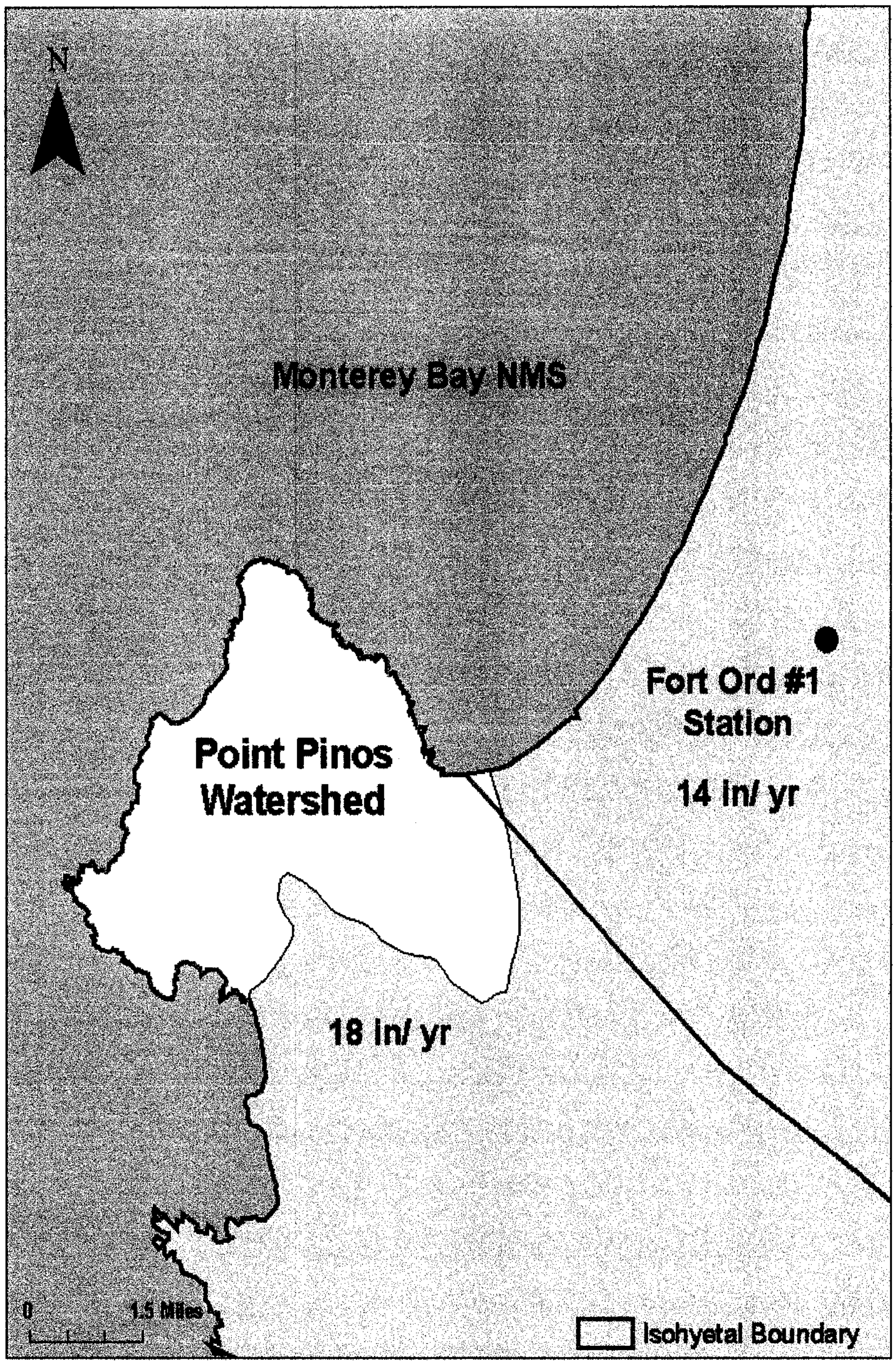

Figure 3: Fort Ord #1 precipitation gauge; precipitation average from1961 – 1999.

Based on the rational method (Viessman *et al.* 2002), the average storm runoff volume (ASV) for the catchment was calculated by multiplying the average storm rainfall (ASRF) at the gauge station, the surface area of the catchment, and the runoff coefficient RV as shown in Equation II:

II. $$ASV = RV * AREA * ASRF$$

where ASV is average storm runoff volume in m^3, AREA is the area of catchment in m^2, and ASRF is average storm rainfall in m. The rational method was first introduced in 1889 as a simplistic method of calculating peak runoff rate from a watershed (Viessman *et al.* 2002). The annual average storm runoff volume (AASV) for the catchment was then calculated by multiplying ASV from Equation II with the average number of storms per year (NSTORM) as shown in Equation III:

III. $$AASV = ASV * NSTORM$$

where AASV is annual average storm runoff in m^3/yr, and NSTORM in average number of storms per year (Wong *et al.* 1997).

Water Quality.

This case study focused on ten common NPS pollutants that a watershed manager would need to identify, estimate, and manage. These include nitrite and nitrate (NO_2, NO_3), total Kjeldahl nitrogen (TKN), total copper (Cu), total lead (Pb), total zinc (Zn), total and soluble phosphorus (P), total suspended solids (TSS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). Nitrite and nitrates generally come from fertilizers used on field crops and maintained grasses and from feed lot runoff. Kjeldahl nitrogen is a measurement of organic nitrogen and primarily comes from animal and human waste, decaying organic matter, and live organic material like tiny algae cells (Tippecanoe 2005). Total suspended solids (TSS), refers to matter dissolved or suspended in runoff water. These particulates vary in composition and can have devastating environment impacts such as clogging the gills of fish and reducing water clarity (Mitchell *et al.* 2000). Reduced water clarity in turn prevents plants from receiving sunlight thereby cutting the photosynthesis and oxygen releasing process and having the potential to cause fish die-offs (EPA 2007). BOD refers to the concentration of biodegradable organic matter present in a sample and COD is the amount of organic pollutants found in runoff. Both BOD and COD are general water quality indicators and are usually cited along with other water quality indicators (for example see The Monterey Bay Sanctuary Citizen Watershed Monitoring Network and Surfrider Foundation).

The site median event mean concentration (EMC) of each pollutant must be estimated for each land use type to incorporate pollutant information into the empirical runoff model. For this model 80 pollutant values (10 pollutants x 8 land use types) were calculated. The EMC is a flow-weighted average concentration which estimates the total mass of pollutants delivered, divided by the total storm flow (Butcher 2003). EMC values are obtained by taking water quality samples at timed intervals throughout the course of a storm event. These samples are then analyzed for content. Since concentration values can vary dramatically depending upon the amount of time a pollutant has had to build up on the runoff surface, taking the median value helps negate some of these variances and provides a much more stable estimate of concentrations in runoff (Butcher 2003).

After contacting local, county, and state agencies, it was determined no reliable EMC datasets for the Point Pinos watershed exist, thus, values from the Nationwide Urban Runoff Program (NURP) were used for this case study (EPA 1983). The NURP was a water quality study funded by the EPA lasting from 1977 to 1982. Countless storm water samples were taken from locations across the U.S. and the results were cataloged to provide an historic baseline that can be referenced when a watershed manager needs a comparative resource (Wood *et al.* 2004). The EPA grouped their median EMC results into four land use types; the four associated EMCs for these land use types were assigned to the eight land use classifications used in this case study. Land use classifications are detailed in Table 4 and were based on the general similarity of characteristics between categories. The NURP median event mean concentrations for urban land use are listed below (Table 5).

Table 4: Point Pinos NURP land use assignments

Point Pinos Land Use Categories	NURP Land Use Categories
Single-family	Residential
Multi-family	Residential
Commercial	Commercial
Public	Commercial
Light Industrial	Commercial
Other Urban	Mixed
Open	Open/Non-urban
Unknown	Mixed

Table 5: Median event mean concentrations for urban land uses

Pollutant	Units	Residential		Mixed		Commercial		Open/ Non-urban	
		Median	COV	Median	COV	Median	COV	Median	COV
BOD	mg/L	10	0.41	7.8	0.52	9.3	0.31	--	--
COD	mg/L	73	0.55	65	0.58	57	0.39	40	0.78
TSS	mg/L	101	0.96	67	1.14	69	0.85	70	2.92
Total Lead	µg/L	144	0.75	114	1.35	104	0.68	30	1.52
Total Copper	µg/L	33	0.99	27	1.32	29	0.81	--	--
Total Zinc	µg/L	135	0.84	154	0.78	226	1.07	195	0.66
Total Kjeldahl Nitrogen	µg/L	1,900	0.73	1,288	0.5	1179	0.43	965	1
Nitrate + Nitrite	µg/L	736	0.83	558	0.67	572	0.48	543	0.91
Total Phosphorus	µg/L	383	0.69	262	0.75	201	0.67	121	1.66
Soluble Phosphorus	µg/L	143	0.46	56	0.75	80	0.71	26	2.11

Source: Nationwide Urban Runoff Program (EPA 1983)

Other researchers (Driscoll *et al.* 1990; Wong *et al.* 1997) have demonstrated that a lognormal distribution adequately represents variable EMCs in storm water runoff from urban areas. When the EMCs are lognormally distributed, site median EMCs can be transformed into the mean event runoff concentrations (ME) using Equation IV:

IV. $$ME = EMC\sqrt{1+COV^2}$$

where ME is mean event concentration in mg/L, EMC is site median event mean concentration, and COV is the coefficient of variation (Wong *et al.* 1997).

In addition, annual loading, which is the total annual pollutant amount, can be estimated for individual pollutants (APL) using Equation V:

V. $$APL_i = AASV * ME_i * CF$$

where APL is annual pollutant loadings in kg/yr, ME is event mean concentration in mg/L, CF is the conversion factor for runoff volume to liters, and *i* is the specific pollutant (Wong *et al.* 1997). This series of equations results in (in this case 80, 10 pollutants x 8 land use types) annual pollutant loads (kg/yr) which are estimated to enter the watershed.

Part II: GIS Integration with the Simple Method

The second half of the Simple Method model as detailed by Wong *et al* (1997) is integrating the empirical runoff model into a GIS. ArcGIS 9.1 (ESRI, Redlands, CA) combined with Excel and Access 2003 (Microsoft, Redmond, WA) was used to perform all of the GIS and database functions. Spatial coverages and data tables were joined using ArcGIS 9.1 in order to perform the calculations given in Part I to estimate the NPS pollutant loadings from runoff for a single event as well as the annual totals in the Point Pinos watershed. The two spatial coverages are the Point Pinos watershed coverage, consisting of one polygon encompassing the entire area of the watershed, and the land use coverage, consisting of 14,946 polygons.

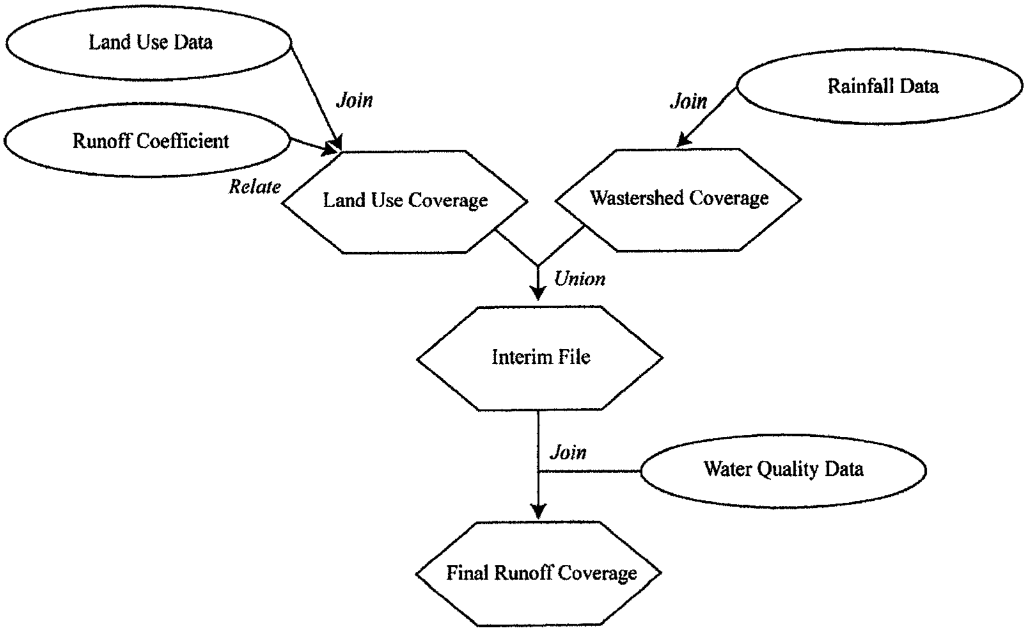

Figure 4: Flow chart depicting GIS data processing (Wong *et al.* 1997).

There are two ways to link attribute tables from Access to spatial coverages in ArcGIS. The first method, called a join, is used when there is a one-to-one or many-to-one relationship between the tables. The second method is a relational link, which is used when there is a one-to-many or many-to-many relationship. The watershed and land use coverages were linked using the join method to the rainfall, runoff, and pollutant data from the empirical model created in Part I of the study to estimate pollutant loading from the Point Pinos basin.

The first step was to link the eight land use assignments, runoff coefficient and rainfall data to the spatial coverages. Land use categories from Table 3 were joined to the land use coverage using the tax use code as the key field. The runoff coefficient information was then related to land use by using a one-to-many relationship link on the land use categories key field. Next, the rainfall data was linked with the watershed coverage using a one-to-one relational join (Equation II and III).

The second step was to overlay the watershed coverage with the land use coverage created in step one to produce the final coverage that was used to estimate the pollutant loadings from the study area. To create the final coverage, the land use and watershed polygons were combined using a union operation. A union operation superimposes coverages together and deletes all duplicate attributes except the one in the first input coverage. The final result of this process was a single coverage that retained the spatial characteristics of the two input coverages as well as the land use, runoff coefficient, and rainfall information (Figure 4).

Lastly, the water quality data were linked by a relational join to the final coverage created in step 2 to create the final runoff coverage (Wong *et al.* 1997). To estimate the NPS pollutant loading for each land use type in the watershed, the ArcGIS field calculator was used to calculate the estimated annual pollutant loadings (Equation V). This produced estimated loads for each of the ten pollutants based on each land use polygon. The field summary tool was then used to sum estimated loading for all pollutants across land use types.

RESULTS

Watershed Summary

The Point Pinos watershed is comprised of approximately 10,610 acres or 42,940,167 square meters in which there are 14,946 separate land use polygons. The predominant land use for the watershed is single-family which covers 33.05% of the watershed area, closely followed by open areas at 30.77%. Light industrial land use makes up the smallest designation, only 0.08% of total land use. Characteristics of the Point Pinos watershed are summarized in Table 6.

Table 6: Land use characteristics

Land Use	Polygon Count	Land Use Percent of total	Area (m^2)
Single-family	11,800	33.05	1,4192,708
Multiple-family	808	2.11	906,083
Commercial	1,131	9.22	3,959,423
Public	356	23.27	9,993,540
Light Industrial	11	0.08	35,897
Other Urban	50	0.46	197,858
Open	632	30.77	13,214,669
Unknown	158	1.02	439,990
Total	14,946	100.00	42,940,167

Precipitation Summary

After analyzing hourly precipitation records form the Fort Ord #1 gauging station, a wet and dry season was identified for the Point Pinos watershed. The wet season spans from 1 October through 30 April with an average of 97.2 percent of total storm event precipitation falling in this period. The dry season is identified as the period between 1 May and 30 September and received an average of 2.8 percent of total storm event precipitation. Table 7 gives the average rainfall for each month arranged by season for the 2001 to 2006 period. The average annual rainfall during the wet season for the period between 2001 and 2006 was 12.16 inches.

Table 7: Average seasonal rainfall for Fort Ord #1 gauge for 2001 – 2006

Month	Rainfall (inches)	Percent of Annual Total
October	0.72	5.73
November	1.01	8.06
December	3.92	31.38
January	1.69	13.50
February	1.95	15.58
March	2.22	17.74
April	0.65	5.23
Wet Season Total	12.16	97.2
May	0.00	0.00
June	0.04	0.35
July	0.00	0.00
August	0.00	0.00
September	0.00	0.00
Dry Season Total	0.04	0.35
Annual Totals	12.20	97.55

The storm event data show an average of 27 storms per wet season with a mean of 11.81 inches of precipitation per year (Table 8). Compared with the 38 year long term average for the Point Pinos watershed, the 2001 – 2006 period wet seasons were approximately 28 percent below the long term average. The average storm volume, intensity, duration, and hours between storms are summarized in Table 9. Since the precipitation totals for two events during the 2004 wet season were not available from hourly reporting data, the gap was filled by using the 24-hour reporting data, thus storm intensity and duration could only be calculated for 135 of the 137 events and time between storms could only be calculated for 132 of the 137 total events. Table 10 shows the average runoff volume produced per event and annually for each land use category.

Table 8: Point Pinos watershed precipitation summary

Storm Year October to April	Number of Storms	Total Precipitation from Storm Events	Total Precipitation for the Year
2001-2002	21	9.18	10.19
2002-2003	22	9.62	10.81
2003-2004	25	9.96	13.16
2004-2005	33	15.57	16.7
2005-2006	36	14.71	15.69
Average	27.4	11.81	13.31

Table 9: Wet season event statistics: 1 October 2001 - 30 April 2006 (mean ± SD)

Storm Events Included*	Storm Volume (inches/storm)	Storm Intensity (inches/hour)	Storm Duration (hours/storm)	Time Between Storms (hours)
137	0.446 ± 0.382			
135		0.041 ± 0.03	12.65 ± 8.95	
132				244.27 ± 632.99

* Two daily records were used to fill missing hourly data in the 2004-2005 wet season, thus, intensity, duration and times between storms, were calculated with these records removed.

Table 10: Runoff volumes summary for Point Pinos watershed

Land Use	Area (m^2)	Mean Number of Storms	Mean Storm Precipitation (m/storm)	Mean Storm Runoff (m^3)	Mean Annual Storm Runoff (m^3)
Single-family	14,192,708	27	0.01133	62,704	1,693,020
Multiple-family	906,083	27	0.01133	5,953	160,742
Commercial	3,959,423	27	0.01133	33,192	896,181
Public	9,993,540	27	0.01133	74,719	2,017,417
Light Industrial	35,897	27	0.01133	301	8,125
Other Urban	197,858	27	0.01133	1,479	39,942
Open	13,214,669	27	0.01133	14,970	404,193
Unknown	439,990	27	0.01133	2,791	75,364
Total	**42,940,167**			**196,111**	**5,294,984**

NPS Pollutant Loading

Table 11 summarizes the Site Median EMC values from the NURP study and how they were applied for this case study. Since the BOD and total Copper mean EMCs for the open land use type were not included in the NURP publication, they were excluded for this case study. The mean runoff event concentrations for each land use and its corresponding set of pollutants are seen in Table 12. Table 13 shows the annual NPS pollutant loading for each land use and pollutant.

Table 11: Median even mean concentrations of NPS pollutants for a given land use from the NURP

	BOD (mg/L)		COD (mg/L)		TSS (mg/L)		Total Lead (mg/L)		Total Copper (mg/L)	
Land Use	Median	CV	Median	CV	Median	CV	Median	CV	Median	CV
Single-family	10.00	0.41	73.00	0.55	101.00	0.96	0.14	0.75	0.03	0.99
Multi-family	10.00	0.41	73.00	0.55	101.00	0.96	0.14	0.75	0.03	0.99
Commercial	9.30	0.31	57.00	0.39	69.00	0.35	0.10	0.68	0.03	0.81
Public	9.30	0.31	57.00	0.39	69.00	0.35	0.10	0.68	0.03	0.81
Light Industrial	9.30	0.31	57.00	0.39	69.00	0.35	0.10	0.68	0.03	0.81
Other Urban	7.80	0.52	65.00	0.58	67.00	1.14	0.11	1.35	0.03	1.32
Open	na	na	40.00	0.78	70.00	2.92	0.03	1.52	na	na
Unknown	7.80	0.52	65.00	0.58	67.00	1.14	0.11	1.35	0.03	1.32

	Total Zinc (mg/L)		Total Kjeldahl Nitrogen (mg/L)		Total Nitrogen NO2 + NO3 (mg/L)		Total P (mg/L)		Soluble P (mg/L)	
Land Use	Median	CV	Median	CV	Median	CV	Median	CV	Median	CV
Single-family	0.14	0.84	1.90	0.73	0.74	0.83	0.38	0.69	0.14	0.46
Multi-family	0.14	0.84	1.90	0.73	0.74	0.83	0.38	0.69	0.14	0.46
Commercial	0.23	1.07	1.18	0.43	0.57	0.48	0.20	0.67	0.08	0.71
Public	0.23	1.07	1.18	0.43	0.57	0.48	0.20	0.67	0.08	0.71
Light Industrial	0.23	1.07	1.18	0.43	0.57	0.48	0.20	0.67	0.08	0.71
Other Urban	0.15	0.78	1.29	0.50	0.56	0.67	0.26	0.75	0.06	0.75
Open	0.19	0.66	0.97	1.00	0.54	0.91	0.12	1.66	0.03	2.11
Unknown	0.15	0.78	1.29	0.50	0.56	0.67	0.26	0.75	0.06	0.75

Table 12: Mean runoff event concentrations of NPS pollutants for a given land use type

Land Use	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Total Lead (mg/L)	Total Copper (mg/L)
Single-family	10.81	83.31	140.01	0.18	0.05
Multiple-family	10.81	83.31	140.01	0.18	0.05
Commercial	9.74	61.18	73.10	0.13	0.04
Public	9.74	61.18	73.10	0.13	0.04
Light Industrial	9.74	61.18	73.10	0.13	0.04
Other Urban	8.79	75.14	101.60	0.19	0.04
Open	na	50.73	216.05	0.05	na
Unknown	8.79	75.14	101.60	0.19	0.04

Land Use	Total Zinc (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Nitrogen NO2 + NO3 (mg/L)	Total P (mg/L)	Soluble P (mg/L)
Single-family	0.18	2.35	0.96	0.47	0.16
Multiple-family	0.18	2.35	0.96	0.47	0.16
Commercial	0.33	1.28	0.63	0.24	0.10
Public	0.33	1.28	0.63	0.24	0.10
Light Industrial	0.33	1.28	0.63	0.24	0.10
Other Urban	0.20	1.44	0.67	0.33	0.07
Open	0.23	1.36	0.73	0.23	0.06
Unknown	0.20	1.44	0.67	0.33	0.07

Table 13: Annual NPS pollutant loading for a given land use type in the Point Pinos Watershed

Land Use	BOD (kg/yr)	COD (kg/yr)	TSS (kg/yr)	Total Lead (kg/yr)	Total Copper (kg/yr)
Single-family	18,298	141,050	237,036	305	79
Multiple-family	1,737	13,392	22,505	29	7
Commercial	8,726	54,830	65,515	113	33
Public	19,643	123,429	147,482	254	75
Light Industrial	79	497	594	1	0
Other Urban	351	3,001	4,058	8	2
Open	0	20,504	87,328	22	0
Unknown	663	5,663	7,657	14	3
Total	49,497	362,366	572,175	745	200

Land Use	Total Zinc (kg/yr)	Total Kjeldahl Nitrogen (kg/yr)	Total Nitrogen NO2 + NO3 (kg/yr)	Total P (kg/yr)	Soluble P (kg/yr)
Single-family	298	3,983	1,619	788	266
Multiple-family	28	378	154	75	25
Commercial	297	1,150	569	217	88
Public	668	2,589	1,280	488	198
Light Industrial	3	10	5	2	1
Other Urban	8	58	27	13	3
Open	93	552	297	95	25
Unknown	15	109	51	25	5
Total	1,409	8,828	4,001	1,702	611

DISCUSSION

The Point Pinos Watershed Summary

The predominant land use types in the Point Pinos watershed are single family, public, and open space which together comprise nearly 90 percent of total land use cover for this watershed. Although much of the watershed-specific data was unavailable, this case study did allow for several very general observations regarding NPS pollution from the Point Pinos watershed. First, single family land use is fairly evenly distributed across the landscape (Figure 5A) and makes up 33 percent of the total land use. EMC values used from the NURP study are highest from single family land use for all 10 pollutants examined and thus, this watershed is likely to have relatively heavy NPS pollution loads.

The other two predominant land use types are open space and public comprising 30.77 and 23.27 percent of the watershed respectively. In this watershed, open space is distributed largely on the western side of the watershed while public land is found mostly on the eastern portion of the watershed (Figure 5B). In terms of EMC values, open space and public land differ considerably for COD, total lead, total P, and soluble P with public land having 40 percent to over double the EMC values relative to open space. A watershed manager can use a GIS based model to visualize the spatial distribution and pollutant loading patterns within the watershed and can, therefore implement localized strategies based upon the specific land use types. For example, the clear spatial division between public and open land use in the Point Pinos watershed may call for distinct management strategies in the western and eastern portions of the watershed.

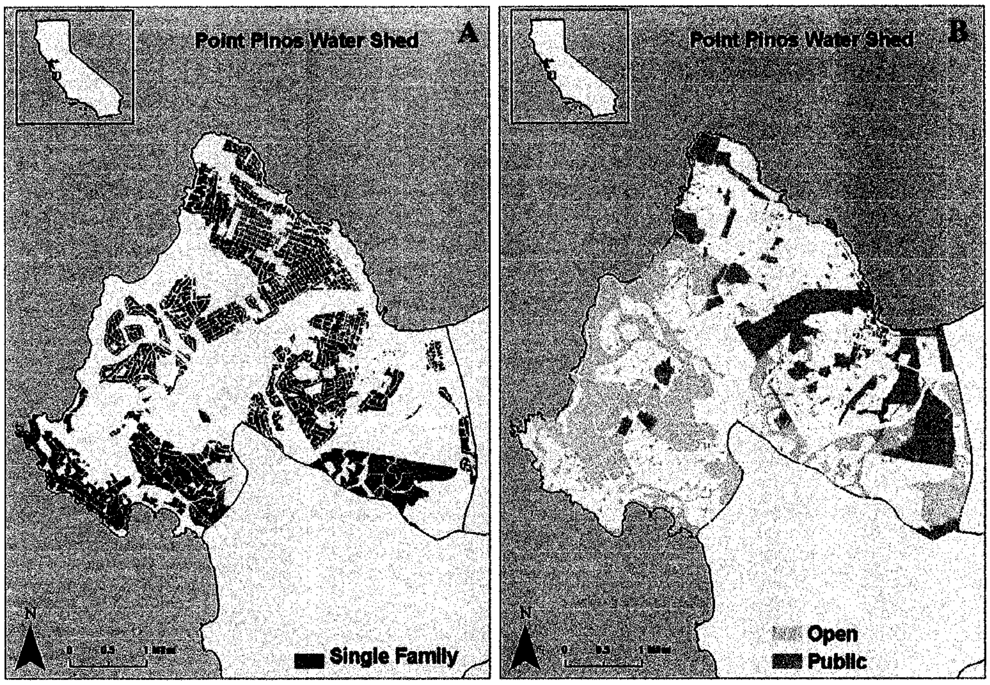

Figure 5: Land use distributions in the Point Pinos Watershed.

Utility of a GIS Based Model for Watershed Management

The first requirement set forth by the EPA guidelines for a watershed manager is to identify causes and sources of NPS pollution. The GIS based Simple Method model is an excellent resource for a watershed manager to better understand spatial patterns and relationships of NPS pollution within a watershed. Although this model does not directly identify causes or sources of NPS pollution, the GIS based model can be used to identify specific land use types or parcels by their location, size, and proximity to objects such as storm drains, creeks, and wells. A watershed manager could use this information in combination with water quality samples taken on location to better understand the potential sources and pathways of the pollutants. For example, if a storm drain emptying directly into the Monterey Bay is showing high levels of TKN (total Kjeldahl nitrogen) whose most common source is human, pet, and livestock waste, the watershed manager could use the model to set up an area buffer around the storm drain's inlets. The parcels that fall within the buffer could be identified and evaluated for their potential contribution to the TKN spike and inspectors could be sent to examine the likely parcels for septic tank leaks or poor waste management practices.

The second EPA requirement is to determine the NPS pollutant load and required reduction within a specific watershed. Federal and state legislation has set the total maximum daily load (TMDL) limits for water bodies in the state of California, including the Point Pinos watershed. To estimate the required reduction needed to bring the watershed within the mandated guidelines a manager must first know the current pollutant loading. Managers are required to address the daily NPS pollutant loading and the required reduction; the ideal modeling solution should estimate daily loading with and without runoff events. The Simple Method model can only estimate NPS pollutant loading from runoff events and can't account for base subsurface flows and urban runoff not associated with precipitation, therefore, this model falls short of a complete solution. However, on days with runoff events, significantly more NPS pollutants enter the storm drains, streams, and eventually the Monterey Bay, compared to days with a base flow. Because the majority of pollutant loading occurs during runoff events, the model can still be a useful tool if the manager makes adjustments for the lack of base flow numbers.

An important aspect of estimating the current pollutant load using a model such as the Simple Method is to understand the potential error associated with the input data. The estimated NPS pollutant loads that are produced by the Simple Method model are entirely dependent on the accuracy, precision, and error rates associated with the input data. For this case study the NURP water quality data was used because the local water quality datasets were composed of limited sample sizes. Thus, data did not necessarily reflect local conditions. However, the national NURP average EMCs did provide a larger more complete set of numbers to feed into the model. For evaluation purposes, the NURP national average EMC numbers used in the case study were compared with the Monterey Bay Sanctuary Citizen Watershed Monitoring Network's 2002 First Flush data and the 2001 Snapshot day grab sample data. First flush is the term used to describe the first precipitation-driven runoff event of the wet season and usually produces a comparatively large amount of NPS pollutants relative to subsequent events. Snapshot day is an annual event where water quality samples are collected independent of weather conditions. Table 14 shows the mean total nitrogen and total phosphorus values from the three studies. Wong *et al.* (1997) found their median pollutant concentrations were generally much higher and in the 90th percentile of the NURP concentrations. The limited EMC values from the Snapshot Data 2001 and First Flush 2002 studies (Hoover 2005) were also generally much higher than the NURP EMC values. By using the NURP EMC numbers it is likely that this case study underestimated the NPS pollutant loads for the Point Pinos Watershed stressing the importance of using locally collected values.

Table 14: Pollutant Comparison

Pollutant	Snapshot Day 2001	First Flush 2002	NURP
Total Nitrogen	1.37	2.35	0.74
Total Phosphorus	0.14	2.28	0.32

all numbers shown in mg/L

Another important aspect to consider when evaluating the Simple Method model's capacity to determine NPS pollutant loading is the ability to account for spatial complexity that will influence NPS pollution runoff within the watershed. A watershed manager's area of interest can vary in size and complexity. The Simple Method model is scalable based on the managers needs and can therefore be used to estimate the NPS pollutant load for any size watershed with any number of land use classifications. The model's flexibility can be important when trying to use existing data sets provided by multiple agencies since often data are initially collected for a variety of purposes and may need to be manipulated before being suitable for input. Once the inputs are defined, the model is run and a pollutant load is calculated, the GIS model can be used to calculate the needed reduction in loading for the watershed manager based on the mandated TMDL for the drainage area.

The third requirement set forth by the EPA's handbook is to track implementation of management measures. The Simple Method model itself is not directly capable of tracking management measures aimed at reducing NPS pollution within a given watershed. Other software solutions are available that could assist a watershed manager track and monitor ongoing management projects. Typically project management software allows a user to create an implementation timeline, manage contacts, store and organize project data, and perform a host of reporting functions. However, the GIS could assist in a limited fashion by providing spatial identification and analyses of planned and ongoing management projects, using the spatial capabilities to assist in deciding the best way to prioritize projects based on site location and proximity to other sites and services.

The fourth suggestion set forward by the EPA is to develop monitoring components. The Simple Method model is very capable of processing the data collected by a host of monitors and data loggers and could, therefore be used to evaluate pre- and post-management NPS pollution in a watershed. For example a manager might identify several storm drains in the Point Pinos watershed with direct outflow into Monterey Bay as targets for close monitoring due to a history of high NPS pollutants in their water quality samples. The watershed manager and staff could set up automated data loggers that would record pollutant concentrations at regularly timed intervals during a runoff event. Those samples could then be converted into EMC totals for each pollutant under review and the model could be run. By repeating this procedure for several runoff events or for several wet seasons, a history could be established that would provide a useful baseline and historical data for comparison. If there are management measures aimed at reducing NPS pollution going on in the area the loading calculations should provide some estimation of the success of those measures.

The fifth requirement for the watershed manager to effectively manage NPS pollution is the ability for the model to integrate with existing data. When an agency considers investing time and financial resources into an additional software or hardware package, it must consider the ability of the new product to integrate with it's existing set of tools. The three key software applications used in executing the Simple Method model are a spreadsheet, database, and GIS package. Out of the three necessary applications most agencies will probably already have software licenses for a spreadsheet and database application so there should be little problem with integrating these packages.

Some agencies may already have an ArcGIS or other GIS software package license. Even if the watershed manager doesn't possess a software license for ArcGIS it's probable that another user in his agency does or a single user license can be purchased for a few thousand dollars. Depending on a watershed manager's specific situation there would probably be little trouble obtaining the necessary software within her existing agency.

In addition to software integration concerns, the quality and format of the data are also extremely important in terms of integration. When running the Simple Method model, a watershed manager will need to collect the necessary input datasets to calculate the NPS pollutant loading from the watershed. Commonly, as in this case, the input data used was not available from a single source and was collected from federal, state, county, and local agencies. Data from multiple agencies will likely be used by any watershed manager attempting to use the Simple Method for the first time so the GIS needs to be able to deal with electronic data and spatial files from many potential sources. ESRI's ArcGIS was chosen as the GIS software solution for this case study based on several criteria including its ability to integrate with older GIS based files, computer-aided design (CAD) files, and attribute data stored in database form. Many public and private agencies have information stored in CAD files and in hard copy. The watershed manager should consider other planning files his agency uses to make sure the model's inputs and outputs can be integrated with each other, and if not, the manager must be prepared to deal with the incompatibility issues.

The last requirement for a watershed manager to manage NPS pollution is a small startup investment for initial implementation of the model. This is an important requirement because often agencies are tasked with many objectives and are only given limited resources to accomplish their goals. The Simple Method model can be utilized by a watershed manager with only a nominal investment to purchase any needed software and the human hours needed to gather and manipulate the readily accessible data to run the model. The low cost of implementation makes the Simple Method model an ideal tool for a watershed manager from a small to medium sized agency and for all mangers that need a cost effective tool to address NPS pollution loading from runoff events in their drainage basin.

Modeling Concerns

This case study was done to explore whether a watershed manger could use readily available data as input to the GIS based Simple Method model to address NPS pollution from runoff events in a chosen watershed by using the model to fulfill six technical requirements set by the EPA. One of the primary benefits of the Simple Method model is the ability to use existing and readily available datasets for inputs, thereby reducing the financial and human resource investment making this method of NPS pollution monitoring available to most any sized organization or institution. This case study identified several challenges that a watershed manager would need to consider when implementing the Simple Method model or other GIS-based pollution runoff models. The two largest challenges in performing this case study were the overlap in state and local managing agencies and the lack of key watershed specific data (e.g.

impervious surface area and EMC values). Four separate public agencies have managing authority over some part of the watershed: the County of Monterey, the cities of Pacific Grove and Monterey, and the California Coastal Commission. However, none collected complete drainage, land use, and water quality data. Although non-watershed specific data sets can be substituted to run the model, the utility of the model to a watershed manger is only as good as the input data.

There were also some common institutional problems and data gaps identified, such as the lack of good file management; without good file management information can get corrupted and lost. For instance, the County of Monterey at one time created a GIS compatible land use layer for the entire county. The existence of the file was documented in a metadata catalog, however, when the county GIS office was contacted only half of the data set was able to be found. The official who created the county wide land use data for a planning project had changed jobs several years prior and the data were never found. Institutional memory should not be relied upon to keep data organized because when people leave the data source can also disappear. Also important is that watershed managers and others working with data files have a method for naming and organizing their date sets so the effort in time and money is not lost when a file turns up missing. The partial land use file for the county was examined to see if the data was usable but it was discovered the coverage was missing information for the city of Monterey and Pacific Grove.

The City of Monterey was contacted for available land use data in electronic form and it was discovered that none existed. The only available land use data was in the form of paper maps from the planning department. The data gap between the county and city records is not an uncommon reality. Each agency sets its own priorities on data collection based on the needs of the entity's obligations. Even if the same type of data is collected by two or more agencies the collection and accuracy standards might be different from one another making it difficult to integrate the two. It wasn't until the California Coastal Commission's parcel shape file was examined for a proxy to land use that the problem was solved.

After reviewing the challenges of performing this case study several recommendations for the implementation of the Simple Method model became clear. These include:

- Obtain the most localized data available including land use, precipitation, and water quality data (see Table 1).
- Form collaborations with surrounding watershed managers and agree upon standardized data collection protocols.
- Create a data sharing agreement with other agencies in the watershed in order to expand available data sets for the input parameters.
- Take advantage of both public and private water quality monitoring programs to obtain local EMC inputs.

Conclusions

This case study demonstrates that a GIS based model such as the Simple Method can provide significant utility in assisting a watershed manager meet the EPA's criteria for monitoring and reducing NPS pollution from runoff events within a study area. Such a GIS-based model uses localized and readily available data to estimate pollutant loading and assist in creating a history of loading values to track the success of management practices. Data inputs are flexible and the model is scalable to the users needs. There are however two main limitations of the Simple Method that mangers should be aware of when choosing this model. First, the Simple Method model does not have the capability to model baseline flow. Although most NPS pollution is transported by runoff events (Stormwater Manager's Resource Center 2006) there is a baseline flow from a watershed that should be considered when addressing NPS pollution management measures. The second limitation of the Simple Method model is that although it has been shown to produce reasonably accurate estimates of NPS pollutant loads, the model's outputs are not extremely precise relative to a more complex model (Stormwater Manager's Resource Center 2006). In general, the Simple Method model is a good choice for a GIS-based tool for watershed managers required to address the problem of NPS pollution.

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