Modeling Agricultural Nonpoint Source Sediment Yield in Imperial Valley, California

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Abstract

Intensive irrigation makes the Imperial and Mexicali Valleys, located on the U.S./Mexico border, a thriving, year-around agricultural region. One by-product of the irrigated agriculture, however, is the nonpoint introduction of sediment, pesticides, and nutrients to the surface water. A parcel-scale erosion model is linked to drainage-scale agricultural information in a GIS and is used to quantitatively estimate sediment yield from a 13,000-hectare study area. Model results provide insight into the causes and patterns of sediment yielded to the drain system. Intensive row crops (e.g., sugar beets and onions) are identified as the major contributors to the sediment problem. Analysis shows that 25 percent of the parcels contribute 87 percent of the sediment to the drain system, and that the northern half of the study area is responsible for over 70 percent of all sediment generated. Several ways in which these patterns could be used to develop mitigation strategies are discussed.

U.S./Mexico Border Agriculture

The U.S./Mexico border region is defined as the area 100 km on either side of the international boundary. There is an intense economic and cultural relationship between people and communities on both sides of the border. The region is characterized by rapidly growing population, constant transboundary movement of people and goods, and a shared environmental setting and resource base that transcend the political boundaries.

This research is focused on the area, which includes the Imperial Valley of California and the Mexicali Valley of Baja California (Figure 1). This area contains hundreds of thousands of acres of irrigated agriculture with year-around production due to the desert climate, water from the Colorado River, and pumped groundwater. In recent years, this area has experienced a rapid increase in population, urban development, and agriculture, which has impacted the watershed, airshed, and ecosystems which encompass the area on both sides of the border. The city of Mexicali, Baja California has increased in population from 511,000 in 1980 to 696,000 in 1995 (USEPA, 1996). Across the border in Calexico, California, the population has increased from 14,400 to 25,000 in the same period.

The combination of urbanization and intensive irrigated agriculture in a desert environment has led to serious water quality problems in the area. Most of the problem with agricultural-induced water contamination is the result of nonpoint source pollution from irrigated fields. Agricultural nonpoint source pollution is the introduction of contaminants such as fertilizers, herbicides, and insecticides into the water from many diffuse sources. The contaminants are carried in dissolved form, as suspended solids, and attached to soil particles that comprise significant portions of agricultural runoff and drainage.

The New River in the Mexicali and Imperial Valleys has been termed one of the most polluted rivers in North America. This river flows into the Salton Sea, which also is the recipient of most of the agricultural drainage of the Imperial Valley. The combination of urban and agricultural pollutants produces one of the most significant water pollution problems in North America.

The intent of this research is to address the problems produced by agricultural runoff by developing a database and methodology to assess agricultural nonpoint source pollution in the Imperial Valley. The Imperial Valley is used in this study, but the implications of the research with regard to farming practices, cropping patterns, and water use are extendable to the Mexicali Valley south of the Border. The Mexicali Valley has the same climate and similar soils as the Imperial Valley and depends completely on irrigation for farm production. In addition, the types of crops grown and the farming practices, such as crop rotations, herbicide, and insecticide applications, are much the same (Imperial County Planning Department, 1993). Thus, insights learned from a better understanding of the Imperial Valley may have direct application to the Mexicali Valley and, in fact, other similar arid agricultural regions.

The Imperial and Mexicali Valleys

The Imperial and Mexicali Valleys form a hydrologically closed basin, located in the Salton Trough that was formerly a part of the Gulf of California (Cory, 1915; Loeltze *et al.*, 1975). The valleys are shown in Figure 1. The agricultural parcels of the Imperial Valley (north) and Mexicali Valley (south) are indicated by the rectangular grid pattern. The cities of Mexicali and Calexico are adjacent to the border in the lower center of the image.

The Salton Sea is the destination for all surface water in the Imperial and Mexicali Valleys. Located north of the U.S./Mexico border, the sea was formed in 1904–05 when irrigation canals accidentally breached, allowing the Colorado River to flow uncontrolled into the Salton Trough. The topographic configuration of the region directs all natural salts and human-induced agricultural chemicals to the Salton Sea (Setmire *et al.*, 1990; Setmire *et al.*, 1993).

The climate in the region is sub-tropical arid. Only about 70 mm of annual average precipitation occurs between August and April with nearly 30 percent of the precipitation occurring in August and September as summer thunderstorms. As reflected by the desert that surrounds the valley,

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Photogrammetric Engineering & Remote Sensing,
Vol. 64, No. 11, November 1998, pp. 1097–1105.

0099-1112/98/6411–1097$3.00/0
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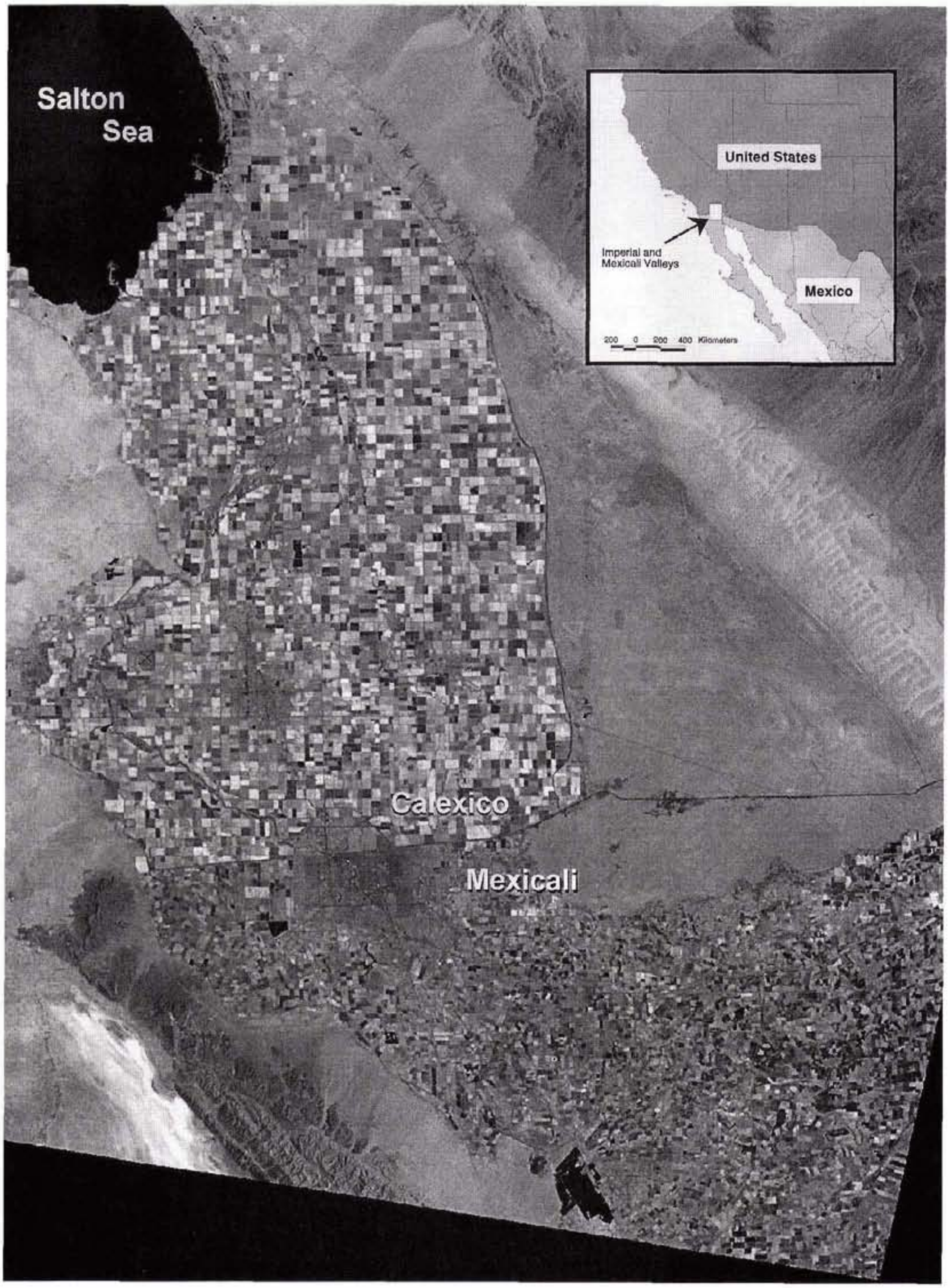

Figure 1. Landsat TM (band 4) image of the Imperial and Mexicali Valleys.

the effect of this rain is slight, and for agriculture the soil moisture content is controlled entirely through irrigation. Evapotranspiration rates exceed 1,800 mm a year, and maximum temperatures exceed 38°C for more than 110 days per year (Cory, 1915; Johnson *et al.*, 1971; Setmire *et al.*, 1990).

Irrigation water was first delivered to the Imperial Valley from the Colorado River through a channel cut in Mexico to the Alamo River channel in 1901. After the breach of the canal, a more reliable canal system was built entirely in the United States. The aptly named "All-American Canal" was completed in 1942, and, since that time, the Valley's population and agriculture has steadily grown. Today, approximately 202,000 hectares (500,000 acres) of Imperial County land is irrigated, and the water sustains very diverse agriculture. Alfalfa, cotton, wheat, and sugar beets are major field crops, while lettuce, carrots, and onions head the list of vegetables (Imperial County, 1991; Imperial County, 1994). All of these crops require high rates of irrigation and agricultural chemical application.

Irrigated agriculture in Mexicali Valley, Mexico is similar to the Imperial Valley, requiring equally intensive irrigation and chemical application (Imperial County Planning Department, 1993). The only point of divergence between the two valleys is the need for ground water pumping in Mexico. Where Imperial Valley agriculture receives all its water from the Colorado River, the Mexicali Valley uses a mix of Colorado River water and ground water for irrigation.

The gross annual diversion from the Colorado River for the Imperial Valley is more than 3.7 billion cubic metres (3 million acre-feet or MAF), or approximately 1.8 metres (6 feet) of water per acre over the irrigated portion of the Valley (IID, 1994). The Salton Sea receives a little more than 1.2 billion cubic metres (1 MAF) of water per year. Irrigation water within the Imperial Valley is distributed by the Imperial Irrigation District (IID) through a network of over 2,500 km of canals and laterals. The IID is the largest irrigation district in the United States, and is a consumer-owned utility responsible for managing the delivery of water and maintenance of the canal system (IID, 1994). The IID keeps strict records on the amount of water applied to each parcel, the date(s) the water was applied, and the crop type. In addition, the IID is also responsible for the system of drainage canals, which carry agricultural runoff to the New and Alamo Rivers, and ultimately to the Salton Sea (Figure 2).

Of the 1.2 billion cubic metres of water discharged to the Salton Sea each year, approximately 85 percent comes from agricultural drainage. Although some of this flow represents a loss to plant usage, considerable discharge is necessary to leach salt from the parcels and maintain soil productivity. The drain water carries sediments and chemicals that evaporatively concentrate in the Sea, a process that has changed the Salton Sea from a fresh water body in the early 1900s to a saltier-than-ocean water body. Pesticides and other biologically active chemicals and elements, such as selenium, also accumulate to higher than acceptable concentrations. All of these factors impair the Sea, and cause it to not fully achieve its designated beneficial uses (USEPA, 1992).

Problem Focus

An important first step toward mitigating nonpoint source pollution is to analyze the study area as a set of smaller, contiguous pollutant source areas. Experience has indicated that in most situations a relatively small part of a study area is responsible for a disproportionately large part of the pollution (Hamlett *et al.*, 1992; Haith and Tubbs, 1981). This approach is well suited to the Imperial Valley, where the smaller source areas can be clearly defined by individual parcels.

Because this research focuses on agricultural nonpoint sources, restriction of the spatial extent of the study to a solely agricultural region is required. The Imperial Valley has many confounding nonpoint and point pollution sources. Examples of these are cattle companies, gravel operations, and urban point and nonpoint sources. If the Imperial Valley were studied as a whole, these different pollution sources would need to be decoupled and modeled individually. A carefully selected study area minimizes non-agricultural pollution sources and focuses the modeling effort on agricultural pollution sources alone. A set of likely sub-drainages which meet this criterion is defined by the IID's drain water quality (DWQ) monitoring program (Snyder, 1996). The Holtville Main Drain (HMD) drainage has been chosen for this study because it has no urban or other complicating land use. Figure 2 highlights the drains that define the HMD study area. The HMD study area has over 165 km (104 miles) of drains that connect 392 parcels in a 13,062-hectare (32,378-acre) drainage.

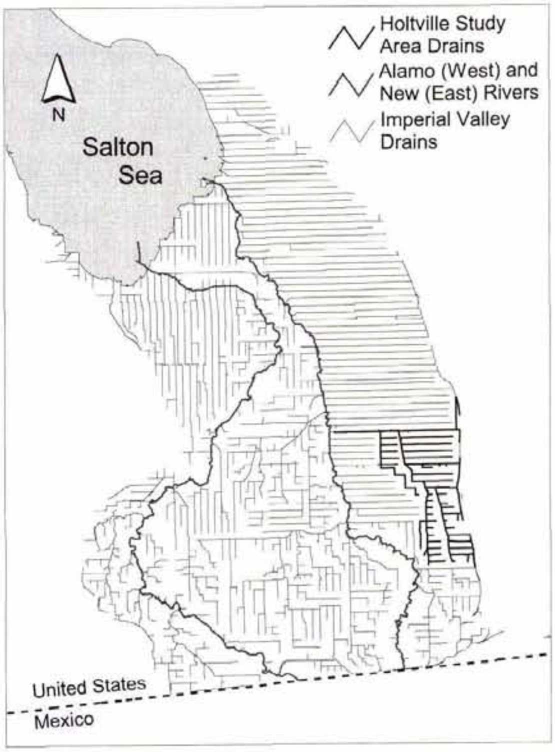

Figure 2. The agricultural drain system in the Imperial Valley.

To further focus the research, a single class of pollutant is investigated. The California Regional Water Quality Control Board (Colorado River Basin) identified four major pollutant classes as water quality problems in the Imperial Valley. The pollutants identified are sediment, selenium, soluble pesticides, and nutrients. The relative detrimental effect of these pollutants is arguable, but sediment, due to its ubiquitous nature and importance in transporting agricultural chemicals, is selected for this research. Irrigation water flowing over agricultural parcels erodes soil and delivers sediment to the drains. Many pesticides chemically bind to the soil and are washed away when the soil erodes. In addition, sediment is the first pollutant in Imperial Valley drain water to have a concentration reduction target set by the California Regional Water Quality Control Board (CRWQCB, 1994).

The balance of this paper describes how a sediment estimation model is linked to a geographic information system (GIS), and how the combination is used to quantitatively model sediment generated in the HMD drainage. The general approach uses modeling to highlight the importance of various physical factors for erosion, and analyzes results from the model application to gain insight into how the physical factors manifest themselves spatially and temporally in terms of erosion. The GIS provides the geocoding and address matching capability required to apply the erosion model to parcels in the HMD drainage.

The Sediment Estimation Model

Texts on soil erosion and sedimentology typically consider the erosion of soil from natural precipitation (Haan *et al.*, 1994; Thomann and Mueller, 1987). In the case of natural precipitation, it is assumed that runoff and sediment transport do not occur until the precipitation rate exceeds the infiltration rate. The Imperial Valley has minimal natural precipitation, and the source of water for crops is predominantly from surface irrigation. Because overland flow is the process of surface irrigation, erosion is directly related to surface irrigation. Overland flow through furrows produces a shear force, which detaches particles from the soil matrix. The shearing force applied by the flowing water is a function of slope steepness and slope length (Haan *et al.*, 1994).

The resistance of the soil to shear force is influenced by the infiltration rate and other physical properties of the soil. Agricultural practices also significantly affect the erosion of soil. Tillage increases erosivity of the soil by breaking up a natural crust that develops after irrigation. At the same time, tillage decreases the potential for erosion by increasing surface area for infiltration. Smoothing of the soil surface and consolidation of the soil structure creates a natural crust that protects against further erosion. Crop root structures significantly decrease the erodability of soils by sheltering the soil from the shear forces of the water, creating small eddies, and binding the soils particles within the root hairs. Therefore, crop species, crop maturity, row density, and plant density all affect soil erosion. Figure 3 summarizes the relationships between these factors and erosion.

To model the effects of these factors, the Agricultural Research Service (ARS) and the Natural Resources Conservation Service (NRCS) started a survey in 1994 of surface irrigated lands as part of the Third Resource Conservation Act (USDA, 1994). The focus of the survey was to identify areas where irrigation induced erosion was at high or alarming rates. Irrigation induced erosion was considered to be erosion that occurs from the application of irrigation water. This survey resulted in physically based, empirically calibrated models for erosion from surface and center pivot sprinkler irrigation.

The model for surface irrigation erosion is a modified form of the Revised Universal Soil Loss Equation (RUSLE) that uses many of the same factors as the RUSLE, but is more detailed in its treatment of crop species and slope. Input parameters for the equation are soil erodability factor (K from the RUSLE), crop class, and slope. Equation 1 is the Surface Irrigated Land Erosion Model (SILEM), developed by the ARS using data collected from irrigated plots in Idaho, Wyoming, and Washington (USDA, 1994): i.e.,

$$Y = \frac{KY_b}{0.49} \tag{1}$$

where Y is sediment yield from the parcel in tons/acre/year, K is the soil erosivity factor from the RUSLE, and Y_b is the base sediment yield that is a function of crop type. The model was developed by the ARS such that soils with K equal to 0.49 have a sediment yield (Y) equaling the base sediment yield (Y_b).

Four crop classes are defined by the SILEM: permanent cover, close growing, row, and intensive row. The classification of crops into crop classes is based on cover and cultural/management practices. Permanent cover crops are perennial ground cover (e.g., alfalfa), which are not cultivated. Close growing crops are annual cover such as broadcast or drilled small grains where the soil is cultivated prior to planting. Row crops are any crops planted in rows, except those described above, which receive less than seven seasonal irrigations or less than two seasonal irrigations following cultivation. Intensive row crops are any crops planted in rows, excluding those described above, which receive more than seven irrigations or more than two irrigations following cultivation. Table 1 presents the classification of crops grown in the HMD study area in 1993. Note the great variety of crop species grown in a relatively small area in a single year. When these crop classes are combined with slope information, the base sediment yield (Y_b) is given by the SILEM (Table 2). The lowest slope class (< 1 percent) is used in this application of the SILEM due to the low topographic relief in the Imperial Valley.

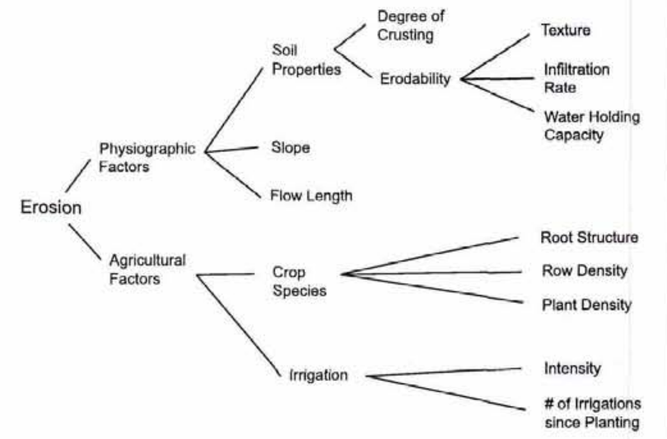

Figure 3. Factors affecting soil erosion from surface irrigated land.

The SILEM results in annual sediment yield estimates in tons per parcel per year. SILEM is used as an event-driven model by assuming sediment leaves the field only during irrigation events. This assumption is correct because there needs to be a means of transportation for sediment to be yielded. Without water there is no transport media, hence no sediment is yielded to the drain system. The method used to divide the annual sediment between irrigation events assumes that the sediment yield is directly proportional to the amount of water delivered on that day. Therefore, as more water is delivered to a parcel, more sediment is yielded from the parcel.

Distributed Nonpoint Source Modeling in a GIS

The datasets required to implement the SILEM model in the Imperial Valley are georeferenced using an address based on the water delivery system. Just as housing units have addresses, parcels in the Imperial Valley have addresses based on the water delivery network (i.e., canals and laterals). This lateral-based addressing system is also used to georeference most other agricultural records in the valley. The water delivery-based address consists of a lateral name, a gate number, and a gate suffix. This type of addressing will be referred to as the lateral-gate-suffix, or LGS, address. Much like a street address, an LGS address references a geographical area, which in the Imperial Valley is often around 160 acres (a quarter section). The area referenced by the LGS address defines the minimum mappable, and, in this case, minimum modelable unit for erosion modeling.

The geographic datasets used in this research may be classified as static spatial data, or as spatially referenced event data. Static spatial data are the basis for the spatial referencing and addressing system in the Imperial Valley. Static spatial datasets are features that are assumed to be unchanging over the course of the modeling period. Examples of this class of dataset include the drains, canals, parcel boundaries, and soil properties. Spatially referenced event data use the LGS addressing system to georeference crop, irri-

Table 1. Categorization of Crops into Four SILEM Crop Classes

Permanent Cover	Close Growing	Row	Intensive Row
Alfalfa	Barley	Cantaloupes	Broccoli
Row Alfalfa	Oats	Casaba-Crenshaw	Cabbage
Alicia Grass	Sorghum Grain	Ear Corn	Cabbage-Chinese
Bermuda Grass	Sorghum Silage	Field Corn	Cauliflower
Buffel Grass	Wheat	Gourds	Garlic
Chinese Grass		Honeydew	Onions
Dichondra Grass		Kava Melons	Potatoes
Grass-Mixed		Lettuce	Red Beets
Klien Grass		Lettuce-Butter	Rutabagas
Pasture-Permanent		Lettuce-Chinese	Sugar Beets
Rye-Grass		Lettuce-Green	Tomatoes
Sudan Grass		Lettuce-Red	
		Lettuce-Romaine	
		Mixed-Fall	
		Mixed-Spring	
		Parsnips	
		Pumpkins	
		Squash	
		Turnips	
		Vegetable-Mixed	
		Watermelons	

gation, and drain water quality (DWQ) information on a daily-event basis. "Daily-event" means that a record is made on the day that there is a change in state at an address. For example, when a crop is planted or harvested the event is recorded. When nothing happens no record is made and the state of the parcel is assumed stationary. The irrigation record is treated somewhat differently. Irrigation events are single day events; therefore, the between-irrigation-event days are times when no water is applied. Several non-spatial datasets are also required to implement the erosion model. These datasets assign crop species to crop classes and relate crop classes to erosion characteristics (Tables 1 and 2).

Arc/INFO GIS was used to provide the capability to relate, manipulate, visualize, and analyze these spatial and non-spatial datasets. The estimation of parcel sediment yield uses the GIS to provide location and date-specific parameters for the SILEM by using LGS addressing, database relations for non-spatial information, and date-specific queries of event data. Arc/INFO was also used to map the spatially addressed results of the SILEM.

Due to the difficulties in obtaining the crop and irrigation data sets and the nuances of data recording procedures in the Imperial Valley, the last full year of data acquisition when this research was performed was 1993. For this reason, the modeling and analysis will reflect the conditions and events of the calendar year 1993. A full calendar year was desired for modeling due to interest in monthly and seasonal patterns, as well as spatial patterns in the erosion estimates. A full year of data makes these patterns possible to find.

Patterns of Erosion Due to Agriculture

Visual presentation of the patterns of erosion provides insight into *where and when* sediment in the drains originates. One of the tenants of nonpoint source studies is that a majority of the pollution comes from a minority of the area. Most often, however, nonpoint source analysis considers space as heterogeneous, but assumes that the source is constant over time. Determining the location, in space and time, of the major contributing areas helps to focus mitigation efforts and maximizes the rate which the pollution is reduced. The adaptation of the SILEM model creates daily estimates of water quality that provide a unique view of spatial and temporal patterns of sediment yield in the HMD study area. The disaggregation of a temporally aggregate model, and the subsequent re-aggregation in temporal terms for analysis constitutes an advancement in the field of nonpoint source modeling.

Table 2. Base Sediment Yield, Y_b, in Tons/Acre/Year Based on Crop Class and Slope

Crop	Slope < 1%	Slope 1%–3%	Slope >3%	Crop Class
Alfalfa	0	2	6	Permanent Cover
Grain, Peas	1	5	11	Close Growing
Beans, Corn	3	14	30	Row
Beets	3	21	47	Intensive Row

Over time, agricultural practices have evolved to maximize farmer utility based on capabilities of the land, expertise of the grower, historical crop rotations, the amount of water available, and the motivation of the grower. The questions addressed by this research concern the consequences of these agricultural practices on soil erosion. Are there parcels which lose a greater than average amount of soil? If there are such locations, is it because of the soil properties or because of the types of crops that are grown? These and other questions are investigated by mapping the results of the SILEM model implementation. Maps produced at several spatial and temporal resolutions highlight various aspects of the model results.

Spatially Aggregated Results

Before analyzing the mapped results, analysis of spatially aggregated data provides some insight into temporal and crop-class characteristics of erosion. Table 3 presents the annual and monthly results of the SILEM. Erosion estimates are presented by crop class and as aggregate monthly and annual sums. The estimated 1993 erosion total was 7,646 tons, or approximately 50 tons of soil per quarter section in production.

When analyzed by crop class, a significant pattern appears. The model indicates that over 82 percent of erosion each year is due to intensive row crops. The contribution of close growing and row crops is only 14 percent. This is partially due to the low per-acre erosion rates in the SILEM model, but is also due to the small number of acres planted in these crops. In terms of acreage, the predominant crop class is permanent cover; however, because of the Y_b for permanent cover crops at less than 1 percent slope is zero, they yield no sediment to the drains. Because the contribution of

Table 3. Annual and Monthly Erosion Estimates (Tons/Crop Class/Month)

	Permanent Cover	Close Growing	Row	Intensive Row	Monthly Total	% of Annual
Jan	0	8	15	40	63	1%
Feb	0	29	131	188	347	5%
Mar	0	95	132	993	1219	16%
Apr	0	121	72	836	1029	13%
May	0	19	161	1112	1291	17%
Jun	0	4	35	312	351	5%
Jul	0	7	0	217	224	3%
Aug	0	4	0	599	603	8%
Sep	0	5	52	480	536	7%
Oct	0	2	211	835	1049	14%
Nov	0	0	146	421	567	7%
Dec	0	2	103	263	368	5%
Annual Class Total	0	295	1056	6295	7646 Annual Total	
% of Annual	0%	4%	14%	82%		

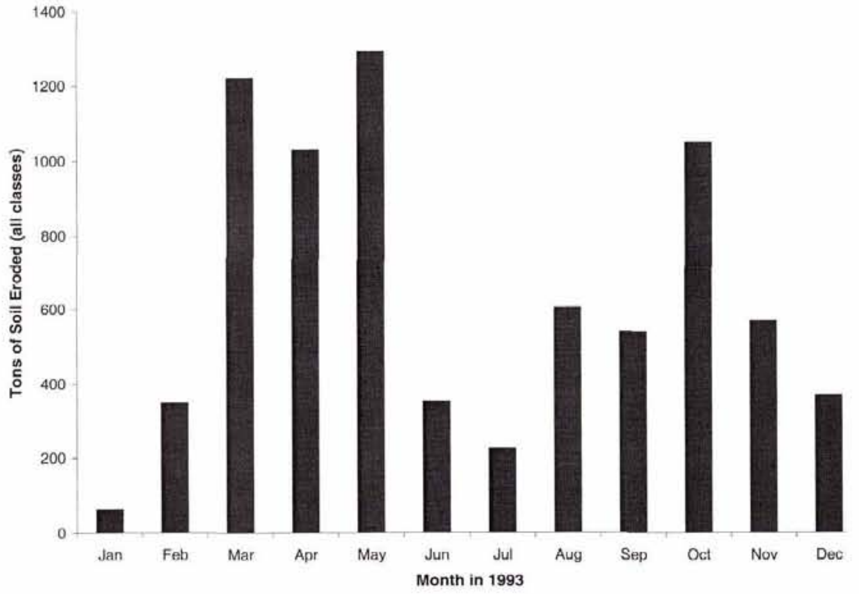

Figure 4. Tons of soil lost vs. month for HMD drainage.

close growing and row crops to the overall sediment yield problem is small, the majority of the following analysis will focus on intensive row crops.

In addition to the values provided by Table 3, Figures 4 and 5 provide a graphical representation of the soil loss estimates aggregated by month. Figure 4 shows the total estimated number of tons lost by month in 1993. The four months with the greatest soil loss are March, April, May, and October, corresponding with the first and second growing seasons for row and intensive row crops. April, May, and June are the highest water use months. The Imperial Valley has a year-round growing season for grass crops such as alfalfa and sudan grass (permanent cover crops), whereas two growing seasons per year exist for vegetable crops such as melons, broccoli, and beets (row and intensive row crops). This seasonal effect is demonstrated when crop class breaks up the monthly tons (Figure 5).

In contrast to the number of acres of permanent cover crops, fewer acres of intensive row crops contribute the majority of the sediment. The dual seasonality of the intensive row crops is readily apparent in Figure 5. Peaks in the number of tons yielded in the spring and fall from intensive row crops correspond to the planting and growing periods for these crops.

Spatially Disaggregated Results

A histogram, Figure 6, provides an un-mapped view of the annual, parcel-scale erosion estimates. Figure 6 shows that

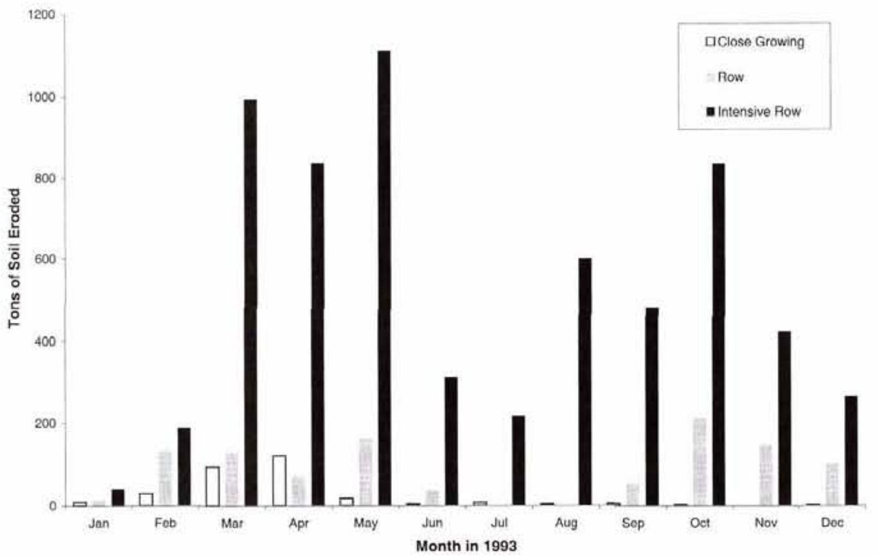

Figure 5. Tons of soil lost vs. month by crop class.

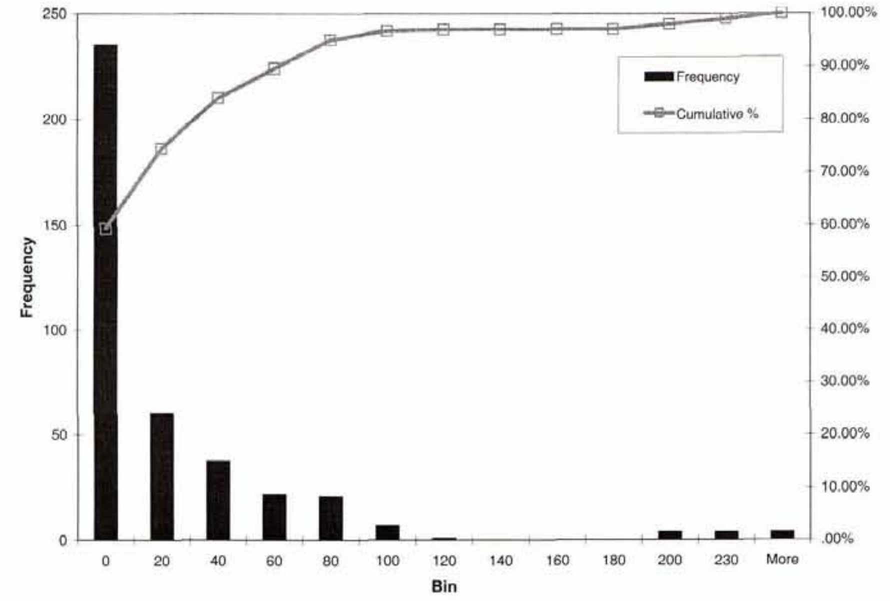

Figure 6. Histogram of annual parcel-scale erosion estimates.

indeed a majority of the erosion comes from a minority of the area, and that the 20 top eroding parcels (5 percent of all parcels) produce 40 percent of the total erosion in the HMD study area. The top 20 percent of the parcels produce over 87 percent of all annual erosion!

Figures 7 and 8 are choropleth maps, which show the distribution of soil loss over the HMD study area. Figure 7 shows that 11 of the top 13 eroding parcels are in the northern half of the study area. These 11 parcels produce 38 percent of the total annual erosion. The northern half of the study area also has a majority of the third tier (50 to 100 tons/1993) erosion estimates. Indeed, the northern parcels are responsible for 70 percent of all erosion over the course of 1993, supporting the conclusion that there are relatively a few "bad actors" that cause much of the erosion problem.

Figures 8a-8c map the erosion estimates based on crop class. There is no map for permanent cover crops because there is no modeled erosion from these crops. Once again, most of the erosion is due intensive row crops. Differentiation between the northern and southern halves of the valley is dominated by the pattern of erosion from intensive row crops.

Significance of Results and Binational Management

The values for erosion presented in the proceeding section should be viewed as conservative estimates. The SILEM was calibrated using data from Wyoming, Idaho, and Washington. These states all have four seasons and significantly shorter growing seasons than the Imperial and Mexicali Valleys. Permanent cover crops have a year-around growing season in the Imperial Valley, and intensive row crops have two, rather than one, crop per year. These differences were highlighted by a study in 1995 by the University of California Cooperative Extension that produced Table 4. Table 4 compares actual Imperial Valley crop yields to average yields for the rest of the nation.

It is readily apparent that the mild winter temperatures significantly raise yields for all classes of crops. Average increase in yield for permanent cover crops was 58 percent, for intensive row crops (sugar beets only) the increase was 60 percent, for close growing crops the increase was 136 percent, and for row crops (cotton only) the increase was 20 percent. It is not unreasonable to assume that the effect of the added production will affect erosion rates as well. If the erosion estimates for each crop class are increased by the percentages indicated above, the annual sediment yield for the HMD study area would increase by 58 percent.

Figure 4 through Figure 8 all showed that, despite the diverse nature of Imperial Valley agriculture, a pattern of erosion does exist. The most likely causes for the pattern are

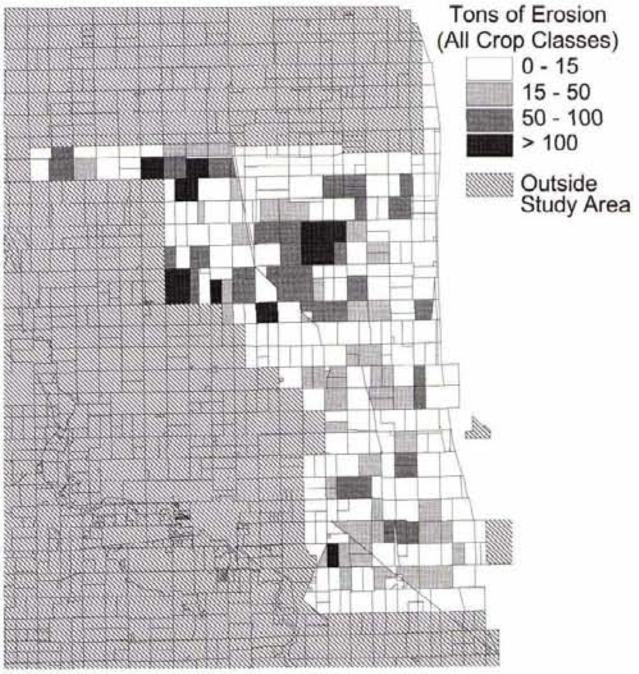

Figure 7. Map of annual erosion from all classes of crops (1993).

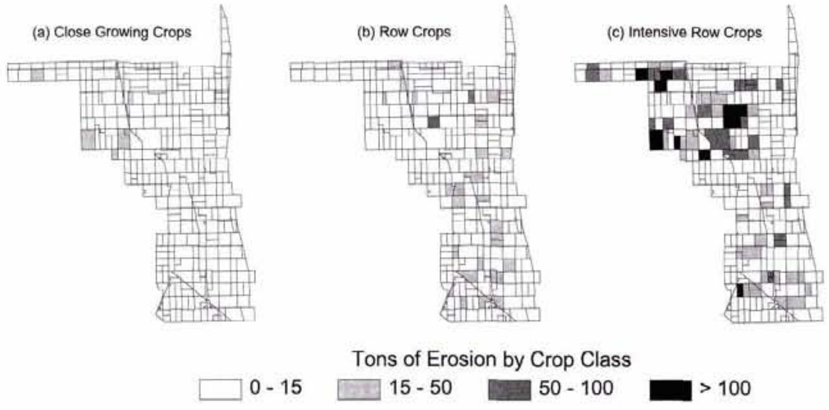

Figure 8. Maps of annual erosion by crop class (1993).

cultural processes, such as familial expertise, historical farming practices, and contractual arrangements. In addition, the pattern suggests mitigation strategies could be designed to take advantage of the clustered high yield parcels. One example of this is shown in Figure 9.

Figure 9 shows that the majority of the erosion, hence a major fraction of the sediment (46 percent), is produced during the spring (March, April, and May). These months are not particularly hot, and a lesser proportion of the water (35 percent) is delivered during the same months. The difference between percentage of sediment and percentage of water delivered presents an opportunity to engineers designing settling ponds or other mitigation structures. The most apparent opportunity comes in the size of the pond or structure. Temporal patterns from the erosion model suggest that the water from the entire year does not need to be captured. Capturing a fraction of the water, for example in the spring and fall, could maximize the annual sediment reduction while minimizing expense and land lost to production.

Figure 6 showed that in a spatially disaggregate sense there are relatively few parcels which contribute a majority of the sediment (20 percent of the parcels created 87 percent of the sediment). Figures 7 and 8 reinforce this and demonstrate that there is a spatial pattern in addition to a temporal pattern of erosion in the HMD study area. Regardless of crop class, the northern half of the study area created over 70 percent of the erosion. These differences are due to the class of crops being grown at those locations. The SILEM model shows that erosion is proportional to both the soil erosivity factor (K) and base sediment yield (Y_b). The range

TABLE 4. ACTUAL CROP YIELDS FOR THE IMPERIAL VALLEY COMPARED TO STANDARD VALUES (ADAPTED FROM UC-COOP, 1995)

Crop	Tons/Acre/Year		Season (months)
	National Average	Actual	
Alfalfa	4.0	9.0	12
Barley	1.2	2.4	NA
Bermuda	8.0	12.0	8
Cotton	0.5	0.6	7
Ryegrass	5.0	6.0	8
Sugar Beets	20.0	32.0	9
Wheat	1.0	2.8	5

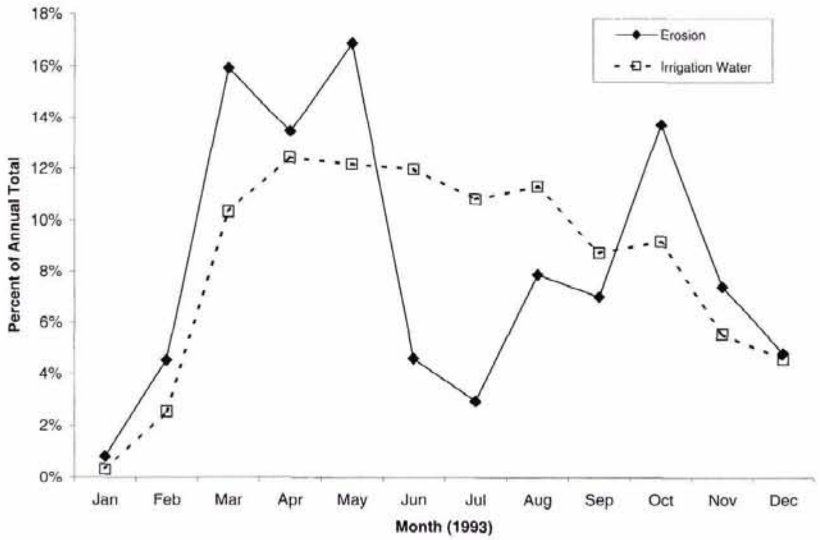

Figure 9. Total soil erosion and water delivery by month (1993).

of soil erodability factors in the study area is approximately 0.3 to 0.5 (1.5 times difference), whereas the range of base sediment yields is 2 to 21 (10 times difference). Therefore, the relative importance of soil properties compared to crop class is small, and this has a large effect on the alternatives for mitigation. These alternatives include, but are not limited to, (1) the construction of sediment capture structures or ponds that could capture the sediment and pollutants before they reach the Salton Sea; (2) the regulation of certain types of crops, possibly as a function of soil properties; and (3) the imposition of best management practices (BMPs), which might include vegetative buffer strips (VBFs) when growing intensive row crops. These VBFs might themselves be a cash crop, like alfalfa, which could partially offset the lost intensive row production.

The ultimate success of a modeling effort like the one presented here is not only by its accuracy, but also by how it positively affects actions taken on the landscape and processes being modeled. In this case, the success of the modeling effort is also measured by its ability to contribute to pollution management in a binational sense. Pursuant to this, the following sequence of events is foreseen. The insight gained from this modeling effort, in conjunction with expert knowledge from agricultural and civil engineering, should be used to evaluate the potential of different mitigation strategies discussed above. The highest potential of these strategies should then be evaluated in pilot programs in the Imperial Valley. During this period the SILEM model should be adapted to agricultural data that are available for the Mexicali Valley. Binational application of what is learned is critical because of the integrating nature of the Salton Trough. Environmental problems do not respect political borders; management must attempt to transcend these boundaries as well. Application of the modified SILEM model to Mexican agriculture would identify where the mitigation measures that have proven most effective could have the greatest affect on soil loss and sediment transported to the Salton Sea.

Acknowledgments

Funding for this research was provided by the U.S. Environmental Protection Agency (EPA) through the Southwest Center for Environmental Research and Policy (SCERP). Computing facilities were provided by the Digitally Integrated Geographic Information Technologies (DIGIT) Laboratory in the Department of Geography at the University of Utah. Agricultural data and data interpretation were graciously provided by the Imperial Irrigation District. All of their support is gratefully acknowledged.

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