# Appendix D Hydrologic and physico-chemical modelling of the watersheds draining into Lingayen Gulf

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## Introduction

There is a growing concern and evidence that Lingayen Gulf is being threatened by the influx of toxic and hazardous substances from the surrounding watersheds and coastal communities. In addition, surface and subsurface inflow of freshwater into the gulf has been reported (Villanoy, 1998). Because of these environmental concerns, there is now an increasing need to evaluate the transport of water and solutes from the different land management units that drain into the gulf. Specifically the migration of nutrients, e.g., nitrogen and phosphorus, and sediments from the upland watersheds and agricultural production areas need to be assessed to establish seasonal and long term impacts on the gulf.

This module therefore comprises a new component of the overall conceptual framework that integrates the biophysical and economic assessment of the interactions among population, human activities, and the environment. The methodologies under this module are aimed to characterize the hydrology, i.e., both quantity and quality, of the watersheds that drain into Lingayen Gulf. This module covers the results of the study, which are:

1. validation of groundwater flow to the gulf as computed by Siringan et. al. (1998) using measured piezometric heads and specific hydraulic conductivities.
2. calculations of water balance in the watershed based on rainfall, evapotranspiration and surface runoff with infiltration or groundwater recharge as the residual value.
3. Simulation of runoff, sediment, and nutrient transport to assess the inputs from the watershed with respect to water quantity and quality.

## Methodology

This component consists of field surveys, groundwater sampling, computation of groundwater flow, water balance calculations and simulation of runoff, sediment, and nutrient transport from the watersheds to Lingayen Gulf. The watershed area draining into the gulf was classified or subdivided into land use criteria and topographic features. Generally, these are the inputs to the runoff/erosion model including the slope, soil and management practices for each land management unit. Also, from groundwater flow computations as done by Siringan, et. al. (1998), a representative subsection covering the wells sampled for water depths and hydraulic gradients were considered in the analysis. This is to study the effect of spatial variability in hydraulic conductivity (K) on ground water flow that was not reflected in the previous computation of discharge for each whole block.

### A. Field surveys and groundwater sampling

Site visits to the study area were undertaken on 16 February and 22-23 March 1999 to gather representative well data within the blocks initially delineated by Siringan et. al. (1998). The first site visit in Sual and Bugallon areas of Pangasinan and the second visit along the coastal communities in La Union involved measurements of well depths and interviews with well owners concerning well profile and history. Details of the interview and well characterization are presented in Table D1.

**Table D1** ***In situ*** **open wells data taken in Pangasinan and La Union on February 16, 1999 and from March 22 to March 23, 1999.**

| **Place** | **Location** | **Ground Elevation** | **Groundwater Elevation** | **Soil Profile** |
|---|---|---|---|---|
| Putot, Bauang, La Union (Station 20) | 16$^0$ 33’ 38” N<br>120$^0$ 20’ 20” E | 15.0m | 10.38m | Sand with pebbles |
| Dili Norte, Bauang, La Union (Station 19) | 16$^0$ 33’ 32” N<br>120$^0$ 19’ 30” E | 10.0m | 7.0m | Sand with pebbles |
| Calumbaya, Bauang, La Union (Station 18) | 16$^0$ 30’ 58” N<br>120$^0$ 19’ 53” E | 15.0m | 6.06m | Sand with gravel |
| Parian Este, Bauang, La Union (Station 17) | 16$^0$ 30’ 31” N<br>120$^0$ 19’ 14” E | 4.0m | 1.25m | Sand with gravel |
| Parian Este, Bauang, La Union (Station 17-A) | 16$^0$ 30’ 20” N<br>120$^0$ 19’ 14” E | 4.0m | 4.25m | Sand with gravel |
| Santiago Norte, Caba, La Union (Station 16) | 16$^0$ 25’ 57” N<br>120$^0$ 20’ 04” E | 3.0m | 0.81m | Sandy |
| Lasud, Caba, La Union (Station 15) | 16$^0$ 25’ 57” N<br>120$^0$ 20’ 25” E | 5.0m | 2.53m | Sandy |
| Lasud, Caba, La Union (Station 15-A) | 16$^0$ 25’ 57” N<br>120$^0$ 20’ 45” E | 15.0m | 3.3m | - |
| ----------, Aringay, La Union (Station 14) | 16$^0$ 24’ 15” N<br>120$^0$ 20’ 00“ E | 1.5m | 0.12m | Sand with grit |
| Sta. Lucia, Aringay, La Union (Station 13) | 16$^0$ 23’ 50” N<br>120$^0$ 21’ 02” E | 10.0m | 7.0m | Sand with grit |
| Sta. Rita West, Agoo, La Union (Station 12) | 16$^0$ 21’ 22” N<br>120$^0$ 20’ 30” E | 1.5m | 0.15m | Sandy |
| Sta. Rita Norte, Agoo, La Union (Station 11) | 16$^0$ 21’ 22” N<br>120$^0$ 21’ 25” E | 10.0m | 3.95m | Sand with grit |
| Ambitacay, Sto. Tomas La Union (Station 10) | 16$^0$ 17’ 53” N<br>120$^0$ 23’ 47” E | 30.0m | 26.75m | Clayey |
| Ambitacay, Sto. Tomas La Union (Station 10-A) | 16$^0$ 17’ 56” N<br>120$^0$ 23’ 55” E | 32.0m | 30.87m | Clayey |
| Namboangan, Sto. Tomas La Union (Station 9) | 16$^0$ 17’ 39” N 120$^0$ 22’ 40” E | 5.0m | 3.0m | Sandy |
| Amlang. Sto. Tomas, La Union (Station 8) | 16$^0$ 14’ 11” N<br>120$^0$ 25’ 48” E | 20.0m | 15.7m | Sand with grit |
| Damortis, Sto. Tomas, La Union (Station 7) | 16$^0$ 13’ 15” N<br>120$^0$ 24’ 29” E | 10.0m | 1.66m | Sand with grit |
| Bulasi, San Fabian, Pangasinan (Station 6) | 16$^0$ 05’ 01” N<br>120$^0$ 25’ 15” E | 3.0m | 1.5m | Sandy |
| Lobong, San Jacinto, Pangasinan (Station 5) | 16$^0$ 05’ 11” N<br>120$^0$ 29’ 28” E | 40.0m | 34.0m | Clayey |
| Quintong, San Carlos City, Pangasinan (Station 4) | 15$^0$ 57’ 47” N<br>120$^0$ 19’ 08” E | 4.0m | 1.6m | Sandy |
| Cawaya Kiling, Urbiztondo, Pangasinan (Station 3) | 15$^0$ 51’ 40” N<br>120$^0$ 19’ 20” E | 6.0m | 3.48m | Sandy |
| Abanon, Urbiztondo, Pangasinan (Station 3-A) | 15$^0$ 52’ 05” N<br>120$^0$ 19’ 33” E | 6.0m | 2.76m | Sand with pebbles |
| Estanza, Lingayen, Pangasinan (Station 2) | 16$^0$ 01’10” N<br>120$^0$ 10’ 27” E | 2.0m | 0.24m | Sandy |
| Pangasinan (Station 2-A) | 16$^0$ 02’ 00” N<br>120$^0$ 11’ 02” E | 1.5m | 0.08m | Sandy |
| Buenlog, Bugallon, Pangasinan (Station 2-B) | 15$^0$ 58’ 55” N<br>120$^0$ 11’ 27” E | 6.0m | 4.24m | Sand with pebbles |
| Cabayawasan, Bugallon, Pangasinan (Station 2-C) | 15$^0$ 57’ 13” N 120$^0$ 13’ 28” E | 5.0m | 3.32m | Sand with grit |
| Laguit Padilla, Bugallon, Pangasinan (Station 1) | 15$^0$ 57’ 01” N 120$^0$ 10’ 53” E | 13.0m | 11.95m | Sand with pebbles |
| Laguit Padilla, Bigallon, Pangasinan(Station 1-A) | -do- | 11.0m | 11.83m | Sand with pebbles |

## B. Groundwater discharge

The open wells inspected were each designated a station number, the locations of the stations, the groundwater surface elevation, and the soil profile characterization. This is presented in Figure D1 (marked Figure 10).

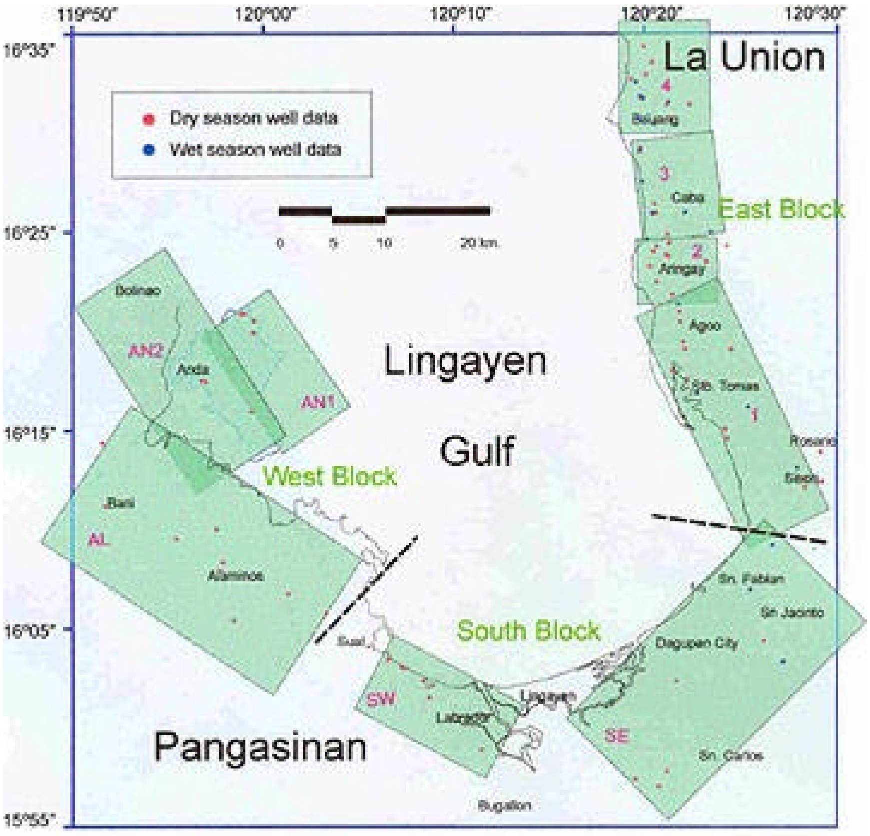


**Figure 10:** Map showing the distribution of wells utilized in the calculation for the groundwater outflow into Lingayen Gulf. Also shown are the pertinent zonations established.

Table D2 shows the groundwater discharge along the coasts of Lingayen Gulf that is within the watershed area. By definition, a watershed area is a land based ecosystem with a defined area (may be composed of several smaller or sub-watersheds), with a specific climate characteristics, water and other resources and in turn is capable of making available and sustaining life support systems for plants, animals and people (Clemente et al.,1998). Each soil profile where a well is located and sampled was designated a corresponding hydraulic conductivity (Bedient and Huber, 1992; Maidment, 1993). The groundwater flow then is computed using the Darcy's Law (Shaw, 1994) as:

$$Q = -K\,A\,i,$$

where: $Q$ = groundwater discharge ($m^3/day$)
$K$ = hydraulic conductivity ($m/day$)
$A$ = cross-sectional area of flow, ($L \times W$)
$L$ = length of coastline (m)
$W$ = width of flow or highest hydraulic head (m)
$i$ = hydraulic gradient, $(h1-h2) / d$
$h2$ = highest hydraulic head (m)
$h1$ = lowest hydraulic head (m)
$d$ = distance from $h1$ to $h2$ (m)

**Table D2. Groundwater discharge along the coastal towns of Lingayen Gulf computed by using different hydraulic conductivities.**

| **Soil Profile** | **Hydraulic Conductivity (K)** |
|---|---|
| Sand with pebbles | 10 +2 m/day or 1000 m/day |
| Sand with gravel | 10 +2 m/day or 1000 m/day |
| Sand with grits | 10 +2 m/day or 1000 m/day |
| Sand | 10 m/day or 10 m/day |
| Sand with grits to sandy | 10 m/day or 10 m/day |
| Sand with pebbles to sandy | 10 +1 m/day or 100 m/day |
| Clayey to sandy | 10 –3 m/day or 0.01 m/day |

| Segment | Hydraulic Conduct-ivity (m/day) | Highest hydraulic head (h1) (m) | Lowest hydraulic head (h2) (m) | Distance between h1 and h2 (m) | Approximate length of coast (m) | Vertical section of flow (m) | $m^3$/day | $m^3$/year |
|---|---|---|---|---|---|---|---|---|
| 4 | 1000 | 10.38 | 7 | 1500 | 5,937.86 | 10.38 | 138,884.1703 | 50,692,722.14344 |
| 4 | 1000 | 6.06 | 1.25 | 1450 | 5,937.86 | 6.06 | 119,365.7283 | 43,568,490.81968 |
| 3 | 10 | 3.3 | 0.81 | 1150 | 9185.438 | 3.3 | 656.3195 | 239,556.62241 |
| 2 | 1000 | 7 | 0.12 | 2000 | 7252.2187 | 7 | 174,633.4263 | 63,741,200.59804 |
| 1 | 10 | 3.95 | 0.15 | 1650 | 11758.244 | 3.95 | 1,069.6439 | 390,420.02116 |
| 1 | 0.01 | 30.87 | 3 | 2300 | 11758.244 | 30.87 | 43.9833 | 16,053.92001 |
| 1 | 1000 | 15.7 | 1.66 | 2450 | 11758.244 | 15.7 | 1,057,896.4116 | 386,132,190.23579 |
| SE | 0.01 | 34 | 1.5 | 10300 | 7201.8856 | 34 | 7.7263 | 2,820.09758 |
| SE | 100 | 2.76 | 1.6 | 10250 | 7201.8856 | 2.76 | 224.9518 | 82,107.39787 |
|  |  |  |  |  | Total |  | **1,492,782.3612** | **544,865,561.8559** |
| SW [a] | 56.16 | 0.39 | 0.09 | 172.93 | 11,801.34 | 0.39 | 448.4086091 | 163,669.14 |
| AN1[a] | 56.16 | 7.72 | 1.7 | 1025.915 | 30372.86 | 7.72 | 77270.76276 | 28,203,828.41 |
| AN2 [a] | 56.16 | 19.09 | 5.85 | 350.4459 | 44150.523 | 19.09 | 1788281.508 | 652,722,750.46 |
| A1 [a] | 56.16 | 7.87 | 1.95 | 3618.3108 | 44319.474 | 7.87 | 32048.8364 | 11,697,825.28 |
|  |  |  |  |  | Total |  | **1,898,049.52** | **692,788,073.29** |
|  |  |  |  | **Grand Total** |  |  | **3,390,831.88** | **1,237,653,635.15** |

[a] - adopted from Siringan et al. (1998) hydraulic conductivity of 0.00065m/sec or 56.16 m/day.
Reference: Maidment (1993)

Using the blocks delineated by Siringan et al. (1998) in Figure D1 (= Figure 10) as the basis for groundwater discharge validation, this study subdivided Block 4 into two equal subsections, Blocks 3 and 2 were maintained as is, Block 1 was also subdivided into three equal subsections and SE Block into two. Other blocks (SW, AN1, AN2, and Al) and its corresponding computed groundwater discharge were used as is in the computation of total groundwater discharge.

## C. Water balance

Daily water balance at the soil surface and unsaturated zone were estimated using the following equation;

$$P = Ro + AET + I$$

where:
P = rainfall depth (cm)
Ro = runoff depth (cm)
AET = actual evapotranspiration (cm)
I = infiltration or recharge to groundwater (cm)

This is also the equation used by JICA (1992) in a study to estimate the groundwater recharge in Metro Manila. However, unlike in the JICA approach where runoff is approximated to be a certain fraction of rainfall, this component was estimated using the US SCS equation which is written as:

$$Qt = ((Rt - 0.2\ St)2 / (Rt + 0.8\ St))$$

where St = retention parameter

$$= 2540/CN - 25.4$$

where CN = curve number, a factor from soil hydrologic tables (Schwab et al., 1987) which reflects the runoff potential of a watershed. The results of the water balance calculations are summarized in Tables D3-6.

In a study by Siringan et al. (1998), freshwater inflows into Lingayen Gulf coming from the watershed were the stream flow and the subsurface discharge. Stream flow was computed based on river discharge while subsurface flow was computed using the modified Darcy's Law (Q=-KAi). In this module however, the whole watershed area of 7485.6 km$^2$ or 748,560 hectares (Siringan et al. 1998) was divided according to its effective land use such as agricultural, grassland or shrubland, forest or wooded , wetland, bareland, and built-up areas. Agricultural area is further subdivided into irrigated rice paddies, unirrigated rice paddies and orchard or fruit trees (LREP-Pangasinan, 1980 and LREP- La Union, 1986). Water balance was calculated for each land-use unit to reflect the effect of farming practices, crop characteristics and soil properties on watershed hydrology.

Runoff depth for built-up areas is computed as 60% of the rainfall (MWSS, 1992 as cited by McGlone and Caringal, 1998). Runoff volumetric rate is also considered as river or stream flow (Clemente et al. 1998) which amounted to 7.03x10$^9$ m$^3$ average per year (Table D6). Siringan et al. (1998) calculated the river discharge in the watershed as 9.88 x 10$^9$ m$^3$ per year. The difference in the volume can be attributed to the different approach in the calculations. Siringan et.al.(1998) calculated the river discharge while in this study climatological data such as precipitation and pan evaporation in the watershed from 1990 to 1998 were used as inputs to the Runoff Submodel of PESTFADE (Clemente, 1991; Clemente, et al., 1993; Clemente et al., 1998). Within the land use classification, grassland or shrubland registered the highest runoff in both provinces of Pangasinan and La Union. This could be attributed also to its areal extent.

The results of water balance calculation (Table D6 and Figure D2) are summarized in Table D5 (ground water recharge or infiltration), Table D3 (surface runoff), and Table D4 (actual evapotranspiration).

## Table 3. Computations for surface runoff ($m^3/yr$) from the watershed area draining into Lingayen Gulf.

| **Land Use** | **Area** | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** |
|---|---|---|---|---|---|---|---|---|---|
| **Pangasinan** | (ha) | | | | | | | | |
| Agricultural areas | | | | | | | | | |
| Irrigated | 35,226 | 309,892,738.70 | 101,823,782.44 | 279,579,779.37 | 143,650,261.90 | 133,775,847.24 | 129,331,836.29 | 198,230,528.84 | 163,113,780.52 |
| Unirrigated | 170,839 | 1,863,284,596.13 | 704,518,510.29 | 1,718,038,986.72 | 930,058,647.70 | 829,347,128.43 | 828,777,402.74 | 1,226,016,171.59 | 1,076,958,902.18 |
| Orchard/fruit trees | 31,990 | 348,904,373.30 | 131,922,729.26 | 321,706,795.20 | 174,155,644.44 | 155,297,178.27 | 155,190,495.81 | 229,574,378.97 | 201,663,058.67 |
| Grassland/ Shrubland | 209,009 | 2,828,238,724.94 | 1,219,915,305.98 | 2,650,163,056.94 | 1,510,277,055.03 | 1,313,223,866.85 | 1,358,359,732.44 | 1,909,749,237.72 | 1,769,762,513.36 |
| Forest or wooded areas | 42,197 | 371,218,528.78 | 121,974,057.44 | 334,906,828.77 | 172,077,729.56 | 160,249,231.42 | 154,925,779.14 | 237,459,082.08 | 195,392,953.97 |
| Wetland areas | 19,445 | 48,786,979.99 | 5,655,074.62 | 33,098,345.64 | 14,225,276.45 | 18,287,331.23 | 20,821,219.88 | 25,176,209.95 | 10,867,010.68 |
| Bareland areas | 9,849 | 43,242,083.75 | 8,644,967.63 | 34,639,445.15 | 15,301,606.86 | 17,320,610.89 | 17,013,674.75 | 24,943,180.35 | 15,146,009.97 |
| Built-up areas | 19,375 | 333,416,625.00 | 214,225,500.00 | 316,095,375.00 | 148,168,834.65 | 128,480,887.68 | 221,595,750.00 | 185,902,431.05 | 173,917,652.80 |
| **Total** | 537,930 | 6,146,984,650.59 | 2,508,679,927.66 | 5,688,228,612.79 | 3,107,915,056.59 | 2,755,982,082.01 | 2,886,015,891.05 | 4,037,051,220.55 | 3,606,821,882.15 |
| **La Union** | | | | | | | | | |
| Agricultural Areas | | | | | | | | | |
| Irrigated | 5,280 | 46,449,601.44 | 15,262,294.08 | 41,906,013.60 | 21,531,635.60 | 20,051,566.64 | 19,385,456.64 | 29,712,632.50 | 24,449,008.15 |
| Unirrigated | 3,559 | 38,816,838.53 | 14,676,867.57 | 35,791,012.32 | 19,375,427.90 | 17,277,357.22 | 17,265,488.42 | 25,540,957.01 | 22,435,724.47 |
| Orchard/fruit trees | 3,447 | 37,595,291.49 | 14,214,993.68 | 34,664,686.56 | 18,765,692.60 | 16,733,647.19 | 16,722,151.89 | 24,737,195.51 | 21,729,683.13 |
| Grassland/ Shrubland | 41,448 | 560,860,243.68 | 241,918,049.47 | 525,546,547.68 | 299,498,889.41 | 260,421,813.57 | 269,372,582.95 | 378,717,119.38 | 350,956,737.05 |
| Forest or wooded areas | 8,372 | 73,650,769.56 | 24,199,985.99 | 66,446,429.14 | 34,140,691.33 | 31,793,885.00 | 30,737,697.54 | 47,112,530.16 | 38,766,495.50 |
| Wetland areas | 558 | 1,400,006.93 | 162,279.85 | 949,800.82 | 408,213.13 | 524,779.16 | 597,492.45 | 722,464.65 | 311,843.25 |
| Bareland areas | 2,120 | 9,307,870.60 | 1,860,831.70 | 7,456,150.24 | 3,293,675.15 | 3,728,266.33 | 3,662,198.24 | 5,369,026.53 | 3,260,182.88 |
| Built-up areas | 2,962 | 50,971,873.20 | 32,750,241.60 | 48,323,845.20 | 22,651,669.07 | 19,641,826.55 | 33,876,986.40 | 28,420,283.91 | 26,588,081.94 |
| **Total** | 67,746 | 819,052,495.43 | 345,045,543.94 | 761,084,485.56 | 419,665,894.18 | 370,173,141.67 | 391,620,054.53 | 540,332,209.65 | 488,497,756.37 |
| **Benguet** | | | | | | | | | |
| Forest or wooded areas | 142,884 | 2,090,575,811.52 | 2,572,047,739.80 | 2,590,098,275.52 | 1,505,830,770.12 | 2,429,074,257.27 | 546,432,710.04 | 2,004,543,417.61 | 767,994,851.61 |
| **Grand Total** | **748,560** | **9,056,612,957.54** | **5,425,773,211.40** | **9,039,411,373.87** | **5,033,411,720.89** | **5,555,229,480.95** | **3,824,068,655.62** | **6,581,926,847.81** | **4,863,314,490.13** |

Note: Average yearly runoff volume = 7,032,867,085.92 $m^3$

**Table 4 Computations for evapotranspiration (m³ / yr) in the watershed area of Lingayen Gulf.**

| Land Use | Area (ha) | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Pangasinan** | | | | | | | | | | |
| Agricultural Areas | | | | | | | | | | |
| Irrigated | 35,226 | 450,751,896.00 | 429,582,831.30 | 408,862,545.84 | 414,045,699.48 | 410,128,744.41 | 401,274,160.92 | 403,224,448.41 | 449,007,328.35 | 439,167,227.06 |
| Unirrigated | ##### | 1,758,794,338.56 | 1,639,033,636.98 | 1,573,442,064.83 | 1,629,526,446.63 | 1,617,053,491.24 | 1,583,652,758.35 | 1,592,526,136.01 | 1,739,427,175.33 | ,721,011,568.24 |
| Orchard/fruit trees | 31,990 | 275,491,002.15 | 262,172,765.40 | 249,713,300.20 | 253,148,386.14 | 250,979,624.35 | 245,171,999.80 | 246,714,877.50 | 273,802,569.95 | 268,836,687.07 |
| Grassland/Shrubland | ##### | 2,215,311,472.08 | 2,108,215,260.48 | 2,008,024,706.24 | 2,035,647,335.68 | 2,018,207,624.72 | 1,971,506,653.76 | 1,983,913,428.00 | 2,201,734,247.44 | 2,161,801,991.14 |
| Forest or wooded Areas | 42,197 | 363,391,491.65 | 345,823,825.62 | 329,388,938.06 | 333,920,051.92 | 331,059,306.31 | 323,398,651.94 | 325,433,813.25 | 361,164,333.99 | 354,613,994.51 |
| Wetland Areas | 19,445 | 257,624,860.50 | 245,170,338.00 | 233,518,894.00 | 236,731,208.00 | 234,703,094.50 | 229,272,106.00 | 230,714,925.00 | 256,045,926.50 | 251,402,091.05 |
| Bareland Areas | 9,849 | 104,390,732.88 | 99,344,105.28 | 94,622,888.64 | 95,924,532.48 | 95,102,731.92 | 92,902,071.36 | 93,486,708.00 | 103,750,941.84 | 101,869,239.18 |
| Built-up Areas | 19,375 | 258,324,937.50 | 246,213,625.00 | 234,916,062.50 | 235,879,000.00 | 233,858,187.50 | 231,077,875.00 | 229,884,375.00 | 255,124,187.50 | 250,497,069.38 |
| **TOTAL** | ##### | 5,684,080,731.32 | 5,375,556,388.06 | 5,132,469,400.31 | 5,234,822,660.33 | 5,191,092,804.95 | 5,078,256,277.13 | 5,105,898,711.17 | 5,640,056,710.90 | 5,549,199,867.63 |
| **La Union** | | | | | | | | | | |
| Agricultural Areas | | | | | | | | | | |
| Irrigated | 5,280 | 67,562,880.00 | 64,389,864.00 | 61,284,115.20 | 62,061,014.20 | 61,473,904.80 | 60,146,697.60 | 60,439,024.80 | 67,301,388.00 | 65,826,462.24 |
| Unirrigated | 3,559 | 36,640,047.36 | 34,145,134.98 | 32,778,283.23 | 33,947,076.63 | 33,687,234.04 | 32,991,413.95 | 33,176,090.46 | 36,236,581.33 | 35,852,938.56 |
| Orchard/fruit trees | 3,447 | 29,684,822.90 | 28,249,750.62 | 26,907,213.06 | 27,277,351.92 | 27,043,662.56 | 26,417,876.94 | 26,584,125.75 | 29,502,890.24 | 28,967,804.32 |
| Grassland/Shrubland | 41,448 | 439,312,325.76 | 418,074,370.56 | 398,205,857.28 | 403,683,624.96 | 400,225,203.84 | 390,964,062.72 | 393,424,416.00 | 436,619,863.68 | 428,701,007.75 |
| Forest or wooded Areas | 8,372 | 72,097,864.02 | 68,612,391.12 | 65,351,664.56 | 66,250,649.92 | 65,683,070.18 | 64,163,175.44 | 64,566,957.00 | 71,655,989.86 | 70,356,384.63 |
| Wetland Areas | 558 | 7,392,886.20 | 7,035,487.20 | 6,701,133.60 | 6,793,315.20 | 6,735,115.80 | 6,579,266.40 | 6,620,670.00 | 7,347,576.60 | 7,214,315.60 |
| Bareland Areas | 2,120 | 22,470,134.40 | 21,383,846.40 | 20,367,603.20 | 20,647,782.40 | 20,470,889.60 | 19,997,196.80 | 20,123,040.00 | 22,332,419.20 | 21,927,382.18 |
| Built-up Areas | 2,962 | 39,492,049.80 | 37,640,503.60 | 35,913,361.40 | 36,060,572.80 | 35,751,363.20 | 35,326,589.20 | 35,144,130.00 | 39,002,727.40 | 38,295,345.52 |
| **TOTAL** | 67,746 | 714,653,010.44 | 679,531,348.48 | 647,509,231.53 | 656,721,388.03 | 651,070,444.02 | 636,586,279.05 | 640,078,454.01 | 709,999,436.31 | 697,141,640.80 |
| **Benguet** | | | | | | | | | | |
| Forest or wooded Areas | 142,884 | 470,088,360.00 | 470,088,360.00 | 470,088,360.00 | 474,374,880.00 | 759,342,729.60 | 470,088,360.00 | 640,120,320.00 | 1,222,944,870.42 | 1,222,944,870.42 |
| **Grand Total** | **748,560** | **6,868,822,101.76** | **6,525,176,096.54** | **6,250,066,991.84** | **6,365,918,928.36** | **6,601,505,978.57** | **6,184,930,916.18--** | **6,388,097,485.18** | **7,573,001,017.63** | **7,469,286,378.85** |

Average yearly AET = 6,691,645,099.43 $m^3$

## Table 5. Computations for groundwater recharge ($m^3/yr$) in the watershed area of Lingayen Gulf as calculated from the water balance.

| | Parameters | | | | | | Ground Water Recharge/Infiltration | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Land Use** | **Area** (ha) | **Kco** | **BD** | **CN** | **Slope %** | **LS** | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** |
| **Pangasinan** | | | | | | | | | | | | | | | |
| Agricultural Areas | | | | | | | | | | | | | | | |
| Irrigated | 35,226 | 1 | 1.35 | 75 | 2 | 0.73 | 310,296,217.30 | 186,675,396.26 | 337,585,376.79 | 151,156,774.52 | 124,438,029.47 | 210,161,556.79 | 206,735,018.09 | 202,374,391.55 | 291,115,272.89 |
| Unirrigated | 170,839 | 0.7 | 1.25 | 80 | 8 | 7.005 | 1,571,768,343.31 | 1,139,000,867.74 | 1,684,566,501.45 | 878,208,302.90 | 794,927,826.25 | 1,180,143,169.91 | 1,101,016,695.66 | 1,133,753,035.85 | 1,482,447,615.33 |
| Orchard/fruit trees | 31,990 | 0.7 | 1.25 | 80 | 8 | 7.005 | 348,164,604.55 | 258,020,655.34 | 360,352,634.60 | 216,430,776.24 | 200,669,495.18 | 272,355,214.39 | 257,657,280.93 | 264,207,105.50 | 331,018,487.59 |
| Grassland/Shrubland | 209,009 | 0.8 | 1.35 | 85 | 20 | 13.83 | 1,310,741,420.98 | 932,517,898.54 | 1,429,617,379.82 | 659,962,492.12 | 634,097,608.10 | 1,065,383,874.80 | 901,630,110.02 | 861,209,315.88 | 1,255,890,582.98 |
| Forest or wooded Areas | 42,197 | 0.7 | 1.4 | 75 | 40 | 38.24 | 548,263,173.57 | 392,387,961.94 | 564,776,252.18 | 343,132,374.37 | 309,294,811.05 | 409,036,281.92 | 405,232,728.74 | 19,121,660.35 | 520,186,739.24 |
| Wetland Areas | 19,445 | 1 | 1.35 | 50 | 0.01 | 0.325 | 284,755,049.52 | 145,560,912.38 | 299,757,275.36 | 140,335,168.18 | 115,939,451.35 | 158,815,579.13 | 190,235,568.67 | 182,694,369.79 | 286,441,378.25 |
| Bareland Areas | 9,849 | 0.8 | 1.5 | 60 | 0.01 | 0.325 | 151,796,481.38 | 92,782,792.09 | 157,609,489.21 | 86,965,291.14 | 74,441,686.85 | 97,198,874.89 | 107,535,764.81 | 108,831,617.43 | 146,768,105.94 |
| Built-up Areas | 19,375 | 1 | 1.1 | 86 | 2 | 0.73 | (2,702,812.50) | (65,479,750.00) | 13,324,187.50 | 5,835,248.56 | 5,262,715.00 | (45,236,750.00) | 28,733,938.94 | 18,946,963.73 | 55,700,567.46 |
| TOTAL | 537,930 | | | | | | 4,523,082,478.11 | 3,081,466,734.29 | 4,847,589,096.91 | 2,482,026,428.03 | 2,259,071,623.25 | 3,347,857,801.83 | 3,198,777,105.86 | 3,191,138,460.08 | 4,369,568,749.68 |
| **La Union** | | | | | | | | | | | | | | | |
| Agricultural Areas | | | | | | | | | | | | | | | |
| Irrigated | 5,280 | 1 | 1.25 | 75 | 2 | 0.942 | 46,510,078.56 | 27,980,641.92 | 50,600,431.20 | 22,656,781.06 | 18,651,927.43 | 31,500,965.76 | 30,987,364.32 | 30,333,753.12 | 43,635,060.49 |
| Unirrigated | 3,559 | 0.7 | 1.25 | 80 | 2 | 0.942 | 32,743,832.11 | 23,728,212.46 | 35,093,697.45 | 18,295,256.69 | 16,560,317.81 | 24,585,308.63 | 22,936,907.97 | 23,618,887.11 | 30,883,059.86 |
| Orchard/fruit trees | 3,447 | 0.7 | 1.25 | 80 | 2 | 0.942 | 37,515,579.62 | 27,802,350.70 | 38,828,869.38 | 23,320,940.47 | 21,622,624.25 | 29,346,934.17 | 27,763,196.23 | 28,468,955.69 | 35,668,043.97 |
| Grassland/Shrubland | 41,448 | 0.8 | 1.3 | 85 | 40 | 71.41 | 259,929,526.56 | 184,925,059.97 | 283,503,491.04 | 130,875,346.87 | 125,746,152.85 | 211,273,346.33 | 178,799,787.57 | 170,784,051.04 | 249,052,207.72 |
| Forest or wooded Areas | 8,372 | 0.7 | 1.3 | 75 | 50 | 111.4 | 108,776,910.42 | 77,850,842.89 | 112,053,150.30 | 68,078,399.84 | 61,364,934.90 | 81,153,915.02 | 80,399,279.69 | 83,154,881.64 | 103,206,469.20 |
| Wetland Areas | 558 | 1 | 1.35 | 50 | 0.01 | 0.325 | 8,171,422.87 | 4,177,062.95 | 8,601,931.58 | 4,027,103.30 | 3,327,035.94 | 4,557,423.15 | 5,459,061.32 | 5,242,656.64 | 8,219,814.30 |
| Bareland Areas | 2,120 | 0.8 | 1.65 | 60 | 2 | 3.32 | 32,674,235.00 | 19,971,521.90 | 33,925,486.56 | 18,719,303.20 | 16,023,593.88 | 20,922,084.96 | 23,147,103.40 | 23,426,036.04 | 31,591,875.78 |
| Built-up Areas | 2,962 | 1 | 1.1 | 86 | 2 | 0.942 | (413,199.00) | (10,010,375.20) | 2,036,967.40 | 892,077.74 | 804,550.29 | (6,915,677.60) | 4,392,770.43 | 2,896,562.92 | 8,515,359.01 |
| **TOTAL** | 67,746 | | | | | | 525,908,386.14 | 356,425,317.59 | 564,644,024.91 | 286,865,209.17 | 264,101,137.35 | 396,424,300.42 | 373,885,470.93 | 367,925,784.20 | 510,771,890.33 |
| **Benguet** | | | | | | | | | | | | | | | |
| Forest/wooded areas | 142,884 | 0.7 | 1.3 | 75 | 50 | 111.4 | 3,686,407,200.00 | 2,900,545,200.00 | 3,414,927,600.00 | 2,443,316,400.00 | 2,451,500,981.27 | 2,100,394,800.00 | 3,014,852,400.00 | 1,743,048,488.66 | 1,970,776,723.52 |
| **Grand Total** | 748,560 | | | | | | 8,735,398,064.25 | 6,338,437,251.88 | 8,827,160,721.20 | 5,212,208,037.20 | 4,974,673,741.87 | 5,844,676,902.25 | 6,587,514,976.79 | 5,302,112,732.94 | 6,851,117,363.53 |

Note: Kco - Crop Coefficient

CN - Curve Number

BD - Bulk Density in g/cm3

slope %- slope of the topography

Note: Average yearly groundwater recharge = 6,519,255,532.50 $^{m3}$

**Table 6 Computations for water balance in the Lingayen Gulf watershed area using the formula: Infiltration = Rainfall - Runoff - AET[a].**

| | Area | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Rainfall** | (ha) | | | | | | | | | |
| Pangasinan /La Union | 605,676 | 18,413.761.752 | 12,346,705,260 | 17,641,524,852 | 12,188,016,663 | 11,491,494,097 | 12,736,760,604 | 13,897,332,910 | 14,004,440,535 | 22,768,573,866 |
| Benguet | 142,884 | 6,247,071,372 | 5,942,681,300 | 6,475,114,236 | 4,423,522,023 | 5,639,915,105 | 3,116,915,870 | 5,658,206,400 | 3,733,987,706 | 5,467,884,912 |
| | | | | | | | | | | |
| ***Total*** | **748,560** | **24,660,833,124** | **18,289,386,560** | **24,116,639,088** | **16,611,538,686** | **17,131,409,201** | **15,853,676,474** | **19,555,539,310** | **17,738.428.241** | **28,236,458,778** |
| **Runoff** | | | | | | | | | | |
| Pangasinan/ La Union/ | | 9,056,612,958 | 5,425,773,211 | 9,039,411,374 | 5,033,411,721 | 5,555,229,481 | 3,824,068,656 | 6,581,926,848 | 4,863,314,490 | 13,916,055,035 |
| Benguet | | | | | | | | | | |
| **AET** | | | | | | | | | | |
| Pangasinan/ La Union/ | | 6,868,822,102 | 6,525,176,097 | 6,250,066,992 | 6,365,918,928 | 6,601,505,979 | 6,184,930,916 | 6,386,097,485 | 7,573,001,018 | 7,469,286,379 |
| Benguet | | | | | | | | | | |
| **Infiltration/ Groundwater Recharge** | | | | | | | | | | |
| Pangasinan/ La Union/ | | 8,735,398,064 | 6,338,437,252 | 8,827,160,722 | 5,212,208,037 | 4,974,673,742 | 5,844,676,902 | 6,587,514,977 | 5,302,112,733 | 6,851,117,364 |
| Benguet | | | | | | | | | | |
| | | | | | | | | | | |
| ***Total*** | **748,560** | **24,660,833,124** | **18,289,386,560** | **24,116,639,088** | **16,611,538,686** | **17,131,409,201** | **15,853,676,474** | **19,555,539,310** | **17,738.428.241** | **28,236,458,778** |

[a] - in $m^3$/year

Mean:

Rainfall - 20,243,767,717.99 $m^3$

Runoff - 7,032,867,085.92 $m^3$

AET - 6,691,645,099.43 $m^3$

Infiltration - 6,519,255,532.5 $m^3$

Parameters used in the calculation such as pan and crop coefficients, bulk density, etc. are derived from literature (Israelsen and Hansen, 1962; Jensen, 1973, LREP-Pangasinan, 1980; LREP-La Union, 1986; Seckler, 1993).

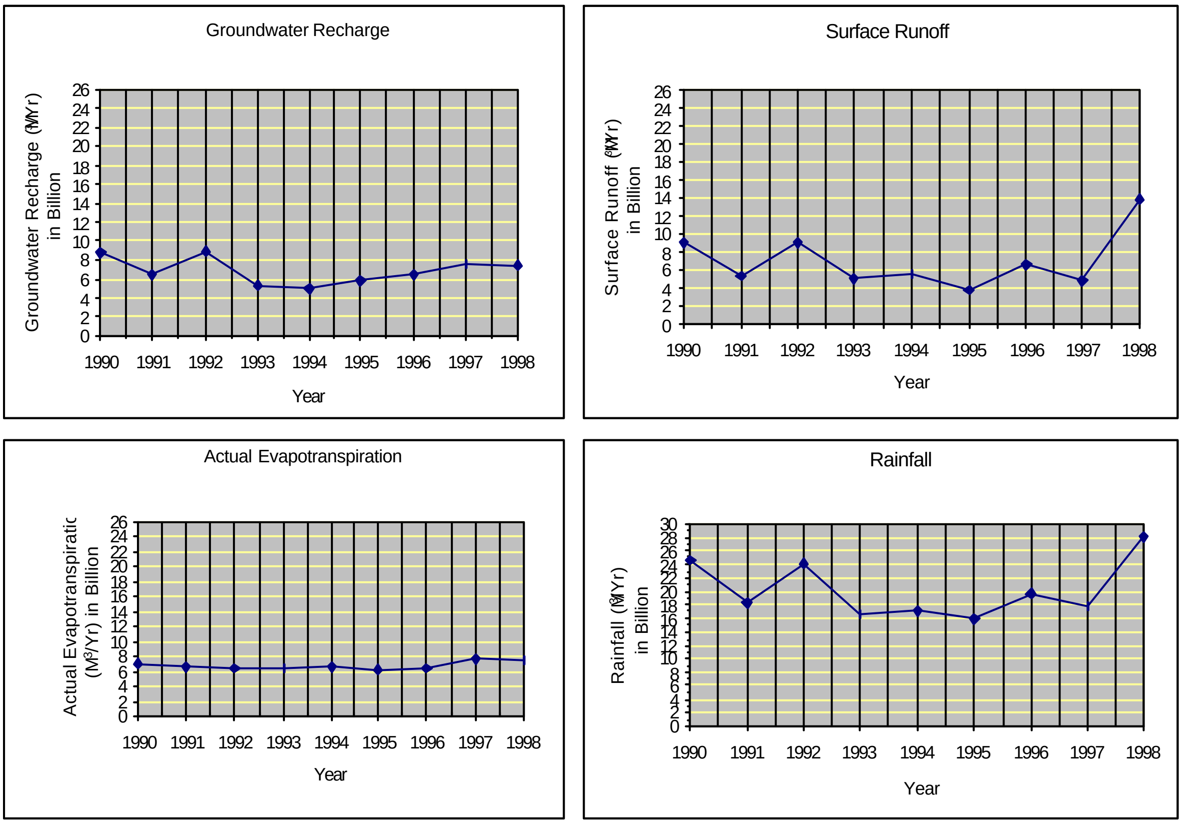


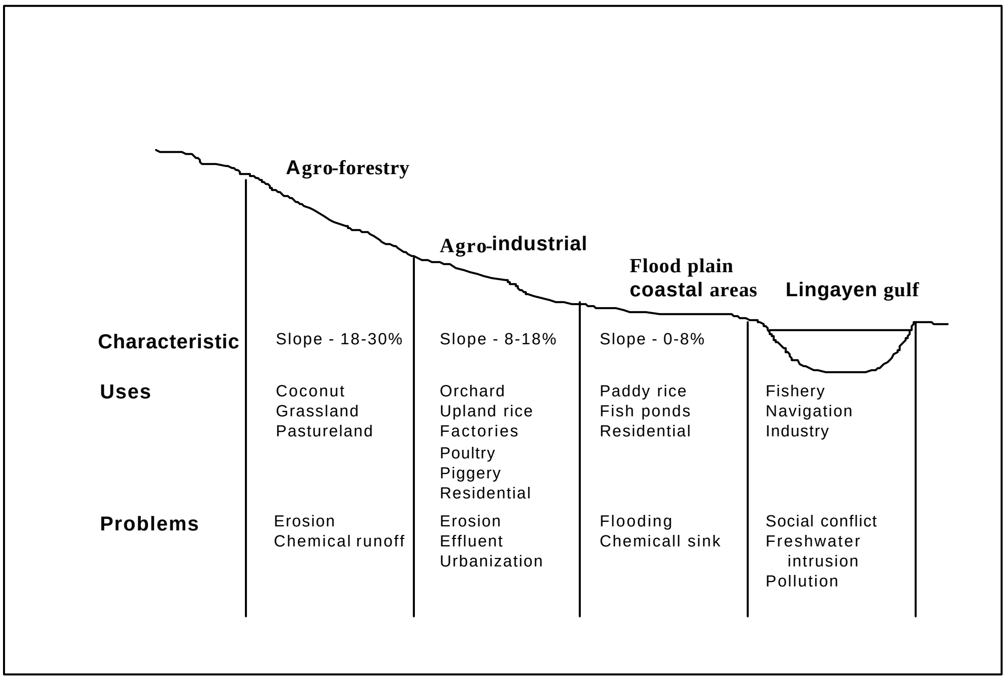
**Figure D2. Overall water balance in the watershed areas draining into Lingayen Gulf.**

## D. Simulation of runoff, sediment, and nutrient transport

A pesticide transport model called PESTFADE model was modified and applied to assess nutrient and sediment transport from the land based production systems into the gulf. PESTFADE, which stands for PESTicide Fate and Dynamics in the Environment is a one dimensional computer model which was developed and validated in Canada (Clemente, 1991; Clemente et al., 1993; Clemente et al., 1998), and recently applied in the Philippines (Clemente et al., 1998). The model simulates the combined effects of runoff, leaching, sorption, degradation, and volatilization on the fate and transport of pesticides in agricultural soils. PESTFADE is an integration of the models and submodels describing water flow, runoff/erosion, heat flow, and solute transport.

In this study, the RUNOFF submodel of PESTFADE was enhanced so it could assess the fate and behavior of nutrients, e.g. phosphorus and nitrogen, at the soil surface as affected by rainfall, soil bulk density, soil erodibility factors and Curve Number (which represents different tillage practices). As a result, Best Management Practices (BMPs) can be evaluated to minimize pollution and sedimentation of surface waters.

Because of the varying land use and cropping practices in the Lingayen Gulf area, the whole watershed surrounding the gulf was categorized into three subareas namely: agro-forest, agro-industrial and flood plain. Details of this classification are presented in Figure D3. This scheme will enable a modular or distributed approach in modeling runoff/erosion based on specific soil properties associated with each land management unit. However, for modelling nutrient transport, it limited the study to major land use for agriculture, e.g., orchard and rice, as they are treated with fertilizers. Since rainfall data with duration is only available during the years 1994, 1995 and 1996, only during these periods where the simulation of nutrient and sediment transport were done. Also, only phosphorus transport was assessed in this phase of the study because of time and data constraints. This is the first attempt to modify the model to incorporate phosphorus transport. Although the relationships for phosphorus partitioning in the adsorbed and dissolved phases have been derived from existing models, some of the constants are not readily measurable or available at the site so it is not possible to validate the modified model predictions. Another limitation is that plant uptake of phosphorus occurs at the crop rootzone and this requires modifications of the leaching/infiltration submodels of PESTFADE which can not be done at this time. So, in modifying the PESTFADE model to simulate phosphorus transport, the following background and methodology explained the various mechanisms incorporated in the model.



| | Agro-forestry | Agro-industrial | Flood plain coastal areas | Lingayen gulf |
|---|---|---|---|---|
| Characteristic | Slope - 18-30% | Slope - 8-18% | Slope - 0-8% | |
| Uses | Coconut<br>Grassland<br>Pastureland | Orchard<br>Upland rice<br>Factories<br>Poultry<br>Piggery<br>Residential | Paddy rice<br>Fish ponds<br>Residential | Fishery<br>Navigation<br>Industry |
| Problems | Erosion<br>Chemical runoff | Erosion<br>Effluent<br>Urbanization | Flooding<br>Chemicall sink | Social conflict<br>Freshwater intrusion<br>Pollution |

**Figure D3. Transect of the Lingayen Gulf basin showing watershed land use classification.**

*Phosphorus Transport in Agricultural Watersheds*

In the soil, water and overland flow systems, phosphorus can exist in two forms: phosphorus in solution (dissolved phosphorus) and in soil or sediments (particulate phosphorus). Also, in these flow regimes, phosphorus which occurs as orthophosphate anion ($PO_4^{-3}$) exists in organic and inorganic forms. Since overland flow and sediment yield from agricultural watersheds vary spatially and temporally, the description of areal and seasonal variations in phosphorus transport is very important (Coote et al., 1982).

Low solubility and high adsorptivity are two of the most important properties of phosphorus in the soil water systems. So much of the phosphorus from fertilizers are strongly adsorbed at soil particles, only around 10% is used by plants. Therefore, the bulk of phosphorus inputs to surface water bodies is likely due to phosphorus transported with sediment. That is why in the Great Lakes basin, 75% of the total phosphorus load comes from Ontario Agricultural watersheds (Miller et al., 1982).

This finding supported the need to assess nutrient transport from the watersheds surrounding the Lingayen Gulf. In modifying the model, it was envisioned to adopt a modeling approach that has been used in existing models, e.g., CREAMS-Knisel, 1980; GAMESP-Rousseau, 1985. Since this has been tested under different climate and watershed conditions, the dissipation of phosphorus is based on the partitioning of phosphorus in particulate and dissolved forms which are mathematically defined below.

*Particulate phosphorus*

Phosphorus adsorbed in sediments and carried by overland runoff (POS) (g/ha) is a function of sediment yield, SL (kg/ha), phosphorus level in surface soil, PO (g/g) and phosphorus enrichment ratio, PER. It is written as:

$$POS = SL * PO * PER$$

The enrichment ratio (PER) is the ratio of sediment PO content to bulk soil PO content and Menzel (1980) indicated that enrichment ratios for cropland range from 2.5 to 7.5. In this study, an average PER value of 5.0 was used.

The phosphorus in dissolved phase (POW, *u*g/l) was modeled using the following equation:

$$POW = K * PO * DI * BD * t^{\alpha} * WS^{\beta} / V$$

Where K, $\alpha$, and $\beta$ are soil constants (Sharpley et al., 1985), PO is phosphorus in soil surface, DI is depth of interaction (10 mm), BD is bulk density (g/cm$^3$), WS is soil water ratio, and V depth of runoff (mm). However, because of the unavailability of some of the constants required in the equation, another approach was used based on Clemente et al. (1993) and Haith (1980). It is written as:

$$POW = (Runoff / Rain) * DT$$

$$DT = (1.0 / (1.0 + (\theta / Kd * BD))) * Pr$$

Where $\theta$ is available moisture, Pr is phosphorus available at soil surface (g/ha), and Kd is sorption coefficient. It should be noted that POS and POW are being computed every runoff event and the remaining phosphorus (PR) is being updated everytime there is partitioning in phosphorus through the adsorbed and dissolved phase. An initial and one time application of phosphorus amounting to 30 lbs/acre was used in the simulation.

The main input data/parameters consist of daily rainfall events and their duration that is currently available from the climatological data base in the gauging station close to the site, other soil and watershed factors, and constants. Details of the input data used in the simulation is presented in Table D5.

## Results of the study

Groundwater Discharge

Using the hydraulic conductivity of Maidment (1993), the total groundwater discharge amounts to 1.24x10$^9$ m$^3$ per year (Table D2). While using another hydraulic conductivity by Bedient and Huber (1992), the total groundwater discharge is 1.17x10$^9$ m$^3$ per year (Table D2A). The derived amounts were computed from actual well measurement conducted during the dry season. Siringan et al. (1998) computed dry season groundwater discharge at 1.27x10$^9$ m$^3$ per year. The reasons for the discrepancies in the results can be attributed to the source(s) of data used in the computations and the selection of hydraulic conductivities. In this study, primary data collected from the site were used.

Water Balance

Table D3 presents the runoff volume. The highest is in 1998 with a volume of 13.9x10$^9$ m$^3$ and the lowest is in 1995 with 3.8x10$^9$ m$^3$ as shown in Figure D2. The high runoff in 1998 can be attributed to higher rainfall intensities during this year. Direct relationships between runoff and rainfall is commonly demonstrated during high rainfall events of short duration which result to higher surface runoff. Mean discharge for the nine year period from 1992-1998 is 7.03x109 m$^3$.

In Table D4 and Figure D2, the highest AET is recorded in 1997 with a volume of 7.57x 10$^9$ m$^3$ while the lowest is in 1995 at 6.18x10$^9$ m$^3$. Mean AET is 6.69x10$^9$ m$^3$. Within the land use area, grassland or shrubland (includes pastureland), Pangasinan and La Union registered the highest AET. This is mainly attributed to the larger area of the grassland and shrubland (accounting to about 28% of the total watershed) which resulted in higher volume of water lost through ET.

Table D5 shows the residual value in the water balance which comprises the infiltration or groundwater recharge. It can be seen that the highest recharge was obtained in 1992 with 8.8x$10^9$ $m^3$ while 1994 is the lowest with 4.97x$10^9$ $m^3$. Mean groundwater recharge is 6.52x$10^9$ $m^3$. Looking at the rainfall and runoff data for 1992, it was found that during this year the rainfall events were not as intense as the other years that resulted in more time for the water to infiltrate into the ground water.

Pangasinan and La Union registered the highest rainfall in 1998 amounting to 375.92 cm with a volume of 2.28x$10^{10}$ $m^3$. The lowest was in 1994 with a rainfall of 189.73 cm and a volume of 1.15x$10^{10}$ $m^3$. Benguet on the other hand had the highest rainfall in 1992 which amounted to 453.17 cm with a volume of 6.48x$10^9$ $m^3$ while the lowest was 218.14 cm which occurred in 1995 with a volume of 3.12x$10^9$ $m^3$. Details are shown in Table D6. 1998 registered the highest total volume of rainfall at 2.82x$10^{10}$ $m^3$ while 1995 was the lowest at 1.59x$10^{10}$ $m^3$. The nine-year mean is 2.02x$10^{10}$ $m^3$. Figure D4 shows the percentage distribution among the different components of the water balance.

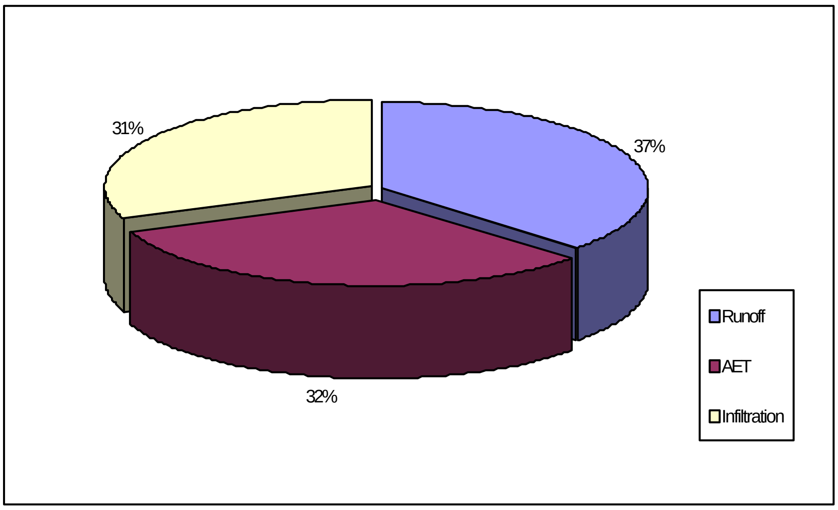


**Figure D4. Average water balance distribution for the nine year period 1990-1998 in the watershed area of Lingayen Gulf.**

Sediment and phosphorus transport

From the preliminary runs for sediment and phosphorus transport at the soil surface, initial results indicate that there were considerable soil loss obtained at the orchard and upland rice farming systems with maximum loss of 345.6 tons/ha-yr, which translate into 2.8 cm of top soil lost every year (Table D8). This is very close to the soil loss obtained by Clemente et al. (1998) for pineapple plantation at the Siniloan watershed that amounted to 322 tons/ha-yr. This high soil loss can be attributed to the steeper slope in these land use units that resulted in higher runoff rates. The environmental implication is that this eroded soil eventually found its way to surface water systems when carried by running water. Because this happens every runoff causing rainfall event, the problem of sedimentation of receiving water courses (e.g., Lingayen Gulf) can worsen over time especially if accumulation of sediments is not controlled.

For phosphorus transport, good correspondence with findings in literature was also obtained. For instance the loss of 0.58 kg/ha/yr in runoff from a row crop obtained by Nelson and Logan (1983) is quite comparable with the total loss of 7.7 mg/l (i.e. 0.96 kg/ha-yr ) for the orchard and upland areas in Pangasinan (Table D7). Although some values obtained are higher than this, this can be attributed to the different practices in the watershed as well as varying soil properties that cause high runoff and thus, high phosphorus partitioning in the dissolved phase. For the particulate part, simulation results are also comparable with the data reported in literature. For instance, a value of 119 mg/l was obtained by the model for upland rice in 1995 (Table D7) which translates into around 10 kg/ha-yr. Although this is quite higher than the 0.5 kg/ha-yr of particulate phosphorus found by Nelson and Logan (1983), the discrepancy can be due to differences in climate and soil characteristics in the two studies. However, the high percentage of phosphorus being partitioned in the adsorbed phase (around 90%, as simulated by the model) has also been reported by various researches (Nelson et al., 1980). This confirms that phosphorus has high affinity for solid phases thus downward movement is considered very slow. Results of the simulation are presented in Table D7.

**Table D7. Phosphorus partitioning in adsorbed and dissolved phases.**

| Year | Land Use | Place | PQT | PXT | PTOT | PR |
|---|---|---|---|---|---|---|
| 1994 | Irrigated Rice | La Union | 7.22 | 210.35 | 217.57 | 6.95 |
| | | Pangasinan | 6.64 | 189.66 | 196.30 | 10.66 |
| | Upland Rice | La Union | 8.70 | 215.90 | 224.60 | 2.68 |
| | | Pangasinan | 7.71 | 220.48 | 228.19 | 0.01 |
| | Orchard | La Union | 8.73 | 215.77 | 224.50 | 2.77 |
| | | Pangasinan | 7.71 | 220.48 | 228.19 | 0.01 |
| 1995 | Irrigated Rice | La Union | 12.04 | 133.23 | 145.27 | 73.69 |
| | | Pangasinan | 10.56 | 126.19 | 136.75 | 69.99 |
| | Upland Rice | La Union | 12.47 | 119.99 | 132.46 | 82.36 |
| | | Pangasinan | 13.88 | 183.09 | 196.97 | 25.60 |
| | Orchard | La Union | 24.19 | 162.85 | 187.04 | 36.12 |
| | | Pangasinan | 14.25 | 183.48 | 197.73 | 27.41 |
| 1996 | Irrigated Rice | La Union | 24.31 | 145.03 | 169.34 | 96.98 |
| | | Pangasinan | 21.57 | 125.74 | 147.32 | 99.16 |
| | Upland Rice | La Union | 25.65 | 136.77 | 162.43 | 109.55 |
| | | Pangasinan | 23.86 | 173.68 | 197.54 | 38.66 |
| | Orchard | La Union | 40.27 | 156.83 | 197.10 | 47.01 |
| | | Pangasinan | 24.24 | 173.45 | 197.69 | 40.24 |

PQT - dissolved phase concentration mg/l

PXT - adsorbed phase concentration mg/l

PTOT- total of PQT and PXT

PR - phosphorus remaining over time

## Conclusion

This module is part of the overall framework for studying the biophysical and chemical interactions affecting Lingayen Gulf. The three objectives of the module consist of: (1) validation of groundwater flow to the gulf, (2) calculations of water balance in the watershed based on rainfall, evapotranspiration, and surface runoff with infiltration or groundwater recharge as the residual value, and (3) simulation of runoff, sediment, and nutrient transport to assess the inputs from the watershed with respect to water quantity and quality. The methodologies for accomplishing these objectives have been described in detail and the sources of information and data for the modelling aspect have also been presented.

Results of the study indicate that ground water flow estimated by Siringan et al. (1998) was comparable with the calculated ground water discharges using measured data. Although this should be expected considering that both methodologies used the modified Darcy's Law in the calculation of discharge, it is still recommended that detailed characterization of the hydraulic properties of the areas surrounding the gulf should be adopted in future studies to reflect the effect of spatial variability.

**Table 8 Soil Loss from the different land use units in Pangasinan and La Union.**

| Place | Land Use | Soil Loss in tons/ha-yr | | | Depth of soil loss (cm) per year | | |
|---|---|---|---|---|---|---|---|
| | | 1994 | 1995 | 1996 | 1994 | 1995 | 1996 |
| La Union | Irrigated Rice | 28.94 | 46.53 | 47.11 | 0.23 | 0.37 | 0.38 |
| | Unirrigated Rice | 36.35 | 58.09 | 58.42 | 0.29 | 0.46 | 0.47 |
| | Orchard | 36.21 | 57.87 | 58.19 | 0.29 | 0.46 | 0.47 |
| | | | | | | | |
| Pangasinan | Irrigated Rice | 28.15 | 45.28 | 45.84 | 0.21 | 0.34 | 0.34 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Unirrigated Rice | 215.05 | 343.71 | 345.64 | 1.7 | 2.7 | 2.8 |
| | Orchard | 175.88 | 281.11 | 282.69 | 1.4 | 2.2 | 2.3 |

The study also indicated that the watersheds in Pangasinan, La Union and Benguet contribute a large amount of freshwater into the gulf. This was established from the water balance accounting using a modified version of the runoff component of the PESTFADE model. Specifically, the percentage distribution among the components of the water balance provided 37%, 32% and 31% for surface runoff, actual evapotranspiration and groundwater recharge or infiltration respectively for the nine year study period. This suggests that the different agricultural and land use units in the watershed surrounding the gulf do not consume much of the rainfall through evapotranspiration nor controlled surface runoff. In effect, freshwater loading to the gulf through overland flows and recharge to ground water has been observed. Since infiltration is around 31% of the total rainfall or $6.52x10^9m^3$, groundwater depletion or seawater intrusion will not be a major concern in the near future, despite the numerous private wells in the area being used for domestic and agricultural purposes.

For sediment transport, results indicate that the upland rice and orchard plantations were susceptible to runoff and erosion. Specifically, a total soil loss of 345.6 tons/ha-yr and 282.7tons/ha-yr was obtained from the two land use units. This was attributed to the larger slope length and the low infiltration capacity of these upland areas.

For the nutrient transport part, it was only possible to consider phosphorus partitioning in the adsorbed and dissolved phases at the soil surface. Results indicated that a high percentage of phosphorus (exceeding 90%) was partitioned into the adsorbed phase which demonstrated the high affinity of this nutrient to solid particles. However, high runoff during the rainy season, loss of phosphorus at the soil surface in both phases can be considerably high which is a cause for concern since the surface water system downstream of the watershed (i.e., Lingayen Gulf) is the receiving end of the chemical residues carried by runoff.

Remedial measures are therefore required to alleviate the potential problem of surface water contamination by sediments and chemical residues from the watershed. Conservation practices such as terracing and increased vegetation can reduce the momentum and impact of rainfall on the soil surface and can therefore be regarded as remedial measures for controlling runoff and soil erosion. However, controlling runoff at the soil surface can have a major effect on the subsurface transport of nutrients. Less runoff means that more water and dissolved nutrients are available for leaching and this has a serious implication on the underlying ground water.

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