USAID FROM THE AMERICAN PEOPLE

The Nature Conservancy
SAVING THE LAST GREAT PLACES ON EARTH

Coastal Resources Center
University of Rhode Island

MANAGING FRESHWATER INFLOWS TO ESTUARIES
Level One Site Profile: Laguna de Términos and its Watershed, Mexico.

Leslie Bach, Rafael Calderon, María Fernanda Cepeda,
Autumn Oczkowski, Stephen Olsen, Don Robadue

Palizada River

Bach, L., Calderon, R., Cepeda, M. F., Oczkowski, A., Olsen, S.B., Robadue, D. (2005). Level One Site Profile: Laguna de Términos and its Watershed, Mexico. Narragansett, RI: Coastal Resources Center, University of Rhode Island.

Level One Site Profile Summary
Laguna de Terminos and Its Watershed, Mexico

ACRONYMS

CNA	Mexican National Water Commission / Comisión Nacional de Agua
CONANP	Mexican National Parks Commission/Comisión Nacional de Areas Naturales Protegidas
CONAPESCA	National Fisheries Commission /Comisión Nacional de Pesca
LOICZ	Land - Ocean Interface in the Coastal Zone Project
NGO	Non-governmental organization
PEMEX	Mexican Petroleum Corporation/ Petroleos Mexicanos
RAMSAR	The Convention on Wetlands, signed in Ramsar, Iran, in 1971
URI	University of Rhode Island
USAID	United States Agency for International Development

Background – the USAID Freshwater to Estuaries Project

In an increasingly crowded world, competition for freshwater is becoming intense. Water is needed to support expanding agricultural activity, cities and industries. As more water is diverted out of rivers and lakes, natural freshwater and estuarine ecosystems – which supply many valuable products and services for humanity – change and loose their original qualities. These trade-offs in the social values associated with water make it necessary to plan and make decisions about water allocation and management in a manner that integrates across the needs of competing user groups. This is best accomplished by planning at scales that integrate watersheds, estuaries, coastlines and the coastal waters as interconnected living systems that sustain human societies.

Estuaries are among the most biologically productive ecosystems on the planet. They depend upon freshwater inflows to sustain their role as nurseries for fish and shellfish, natural treatment plants for processing wastes and a host of other ecological and economic functions of great importance to human society. Yet around the world the growing competition for freshwater for agriculture, industry, and domestic uses is reducing, and in some cases eliminating, freshwater flows to estuaries. This is expressed not only in change to the volume of water but also the timing of freshwater inflows and the quality of that water. Too often, the allocation of freshwater among its human users ignores the impacts that such decisions have upon estuaries and other natural resources. The results can be dramatic and seen as collapsed fisheries, changes in shoreline dynamics, and losses in important habitats and the species that depend upon them.

Our Approach

With funding from The US Agency for International Development (USAID), the Coastal Resources Center of the University of Rhode Island and The Nature Conservancy have joined together to develop and apply low-cost methods for addressing the impacts of changes in freshwater inflows on estuaries. Our emphasis is upon methods that may be applied in less-developed countries where data availability and management capacity may be limited. The design of these methods will be based upon the "learning by doing" philosophy of adaptive management in which resource management agendas are developed using the best information available. Critical information gaps are being identified and will be filled as time, funding and research capabilities allow. A critically important element of adaptive management is the synthesis of the information that is most relevant to evaluating the trajectory of change, including both the impacts of the actions that have been taken and the likely consequences of a range of potential future decisions.

We have selected two pilot sites for initial testing of our methods, one in the Dominican Republic and the other in Mexico. Our site teams in these countries will work with governmental and non-governmental stakeholders to assess the issues posed by changes to freshwater inflows and then formulate action strategies to address the consequences of such changes.

The steps to be taken at each pilot site are as follows:

1. Develop a Level One Site Profile based upon existing information on the condition of the watershed and its estuary, trends in human activities influencing this condition, and the management issues posed by changes to freshwater inflows.
2. Undertake short term research and consultations to confirm or correct initial findings and fill in major information gaps to produce a Level Two Site Profile that contains sufficient information to reasonably estimate the impacts of future changes to freshwater inflows
3. Work with stakeholders to develop plausible scenarios for the future desired condition and desired human activities in each linked watershed-estuary system.
4. Work with stakeholders to assess management options that draw upon the scenarios and identify the monitoring and actions required to progress toward the future conditions desired for the watershed and its estuary.

The project team will draw from the experience gained at the two sites to prepare a Methods Guide describing simple but robust, participatory methods for forecasting and addressing the impacts of changes to freshwater flows to estuaries.

Level One Site Profiles

As the first step in our process, the Level One profile draws together the available secondary information and identifies the information and the consultations that are needed in order to make plausible estimates of the changes that may be brought by changes to freshwater inflows to the estuaries in the two pilot sites. A Level One profile is no more than an exercise in "doing the homework" on each site and setting the stage for an analysis that will place these issues posed by changes to freshwater flows within the larger context of trends in the development and conservation in the ecosystem.

The following questions are addressed in the Level One profiles:

- How have human activities and the condition of the estuary and its watershed evolved in recent decades? How important are changes to freshwater flows compared to other issues in this ecosystem?
- What are the interests of the various stakeholder groups and what do they see as the major issues, the major choices and the outcomes they desire?
- What are the likely future changes to the quantity, timing, and quality of freshwater flows to the estuary?
- What are the potential impacts of such change on the estuary and the goods and services it generates for the associated human population?
- What monitoring activities could be implemented to evaluate the potential impacts of land and management activities on the estuary?

1. The National Context

National authorities and interests play an important role in making decisions on the use of the water resources, forests, wetlands, coastal lagoons, oil and gas reserves, and fisheries resources which can be found in and near the Laguna de Terminos and its watershed. Mexico's water resources are managed by the National Water Agency (Comisión Nacional de Agua, CNA). This powerful and formerly highly centralized decision body has delegated some important functions and decisions to the country's twelve water management regions as part of a broad process of decentralization and greater stakeholder involvement and responsibility for water resource management. The Laguna de Terminos watershed crosses two of these: Region XI (Chiapas and Tabasco) and Region XII (Campeche, Yucatan, and Quintana Roo). The water management plans for each region cover a wide range of topics including water supply, agricultural irrigation, water rights, flood control, electricity production and waste water management. As a result the data and programs presented in each CNA plan are sliced up according to the water resources region, making it difficult to assemble a clear understanding of their implications for the Usumacinta and Candelaria watersheds which discharge to the Laguna de Terminos.

The National Parks Agency, CONANP, is responsible for all Mexican parks and reserves and is the institution most advanced in using ecosystem oriented tools and policies. The Laguna de Terminos was declared a federally designated Flora and Fauna reserve ("Area de Protección de Flora y Fauna) in 1994. The Reserve boundaries incorporate portions of the lower watersheds of the Candelaria, Chumpon and Palizada, and abut the biosphere reserve Pantanos de Centla that had been created in 1992. Both the Reserves, an area of 1,007,723 hectares**,** are administered by a five person team from CONANP.

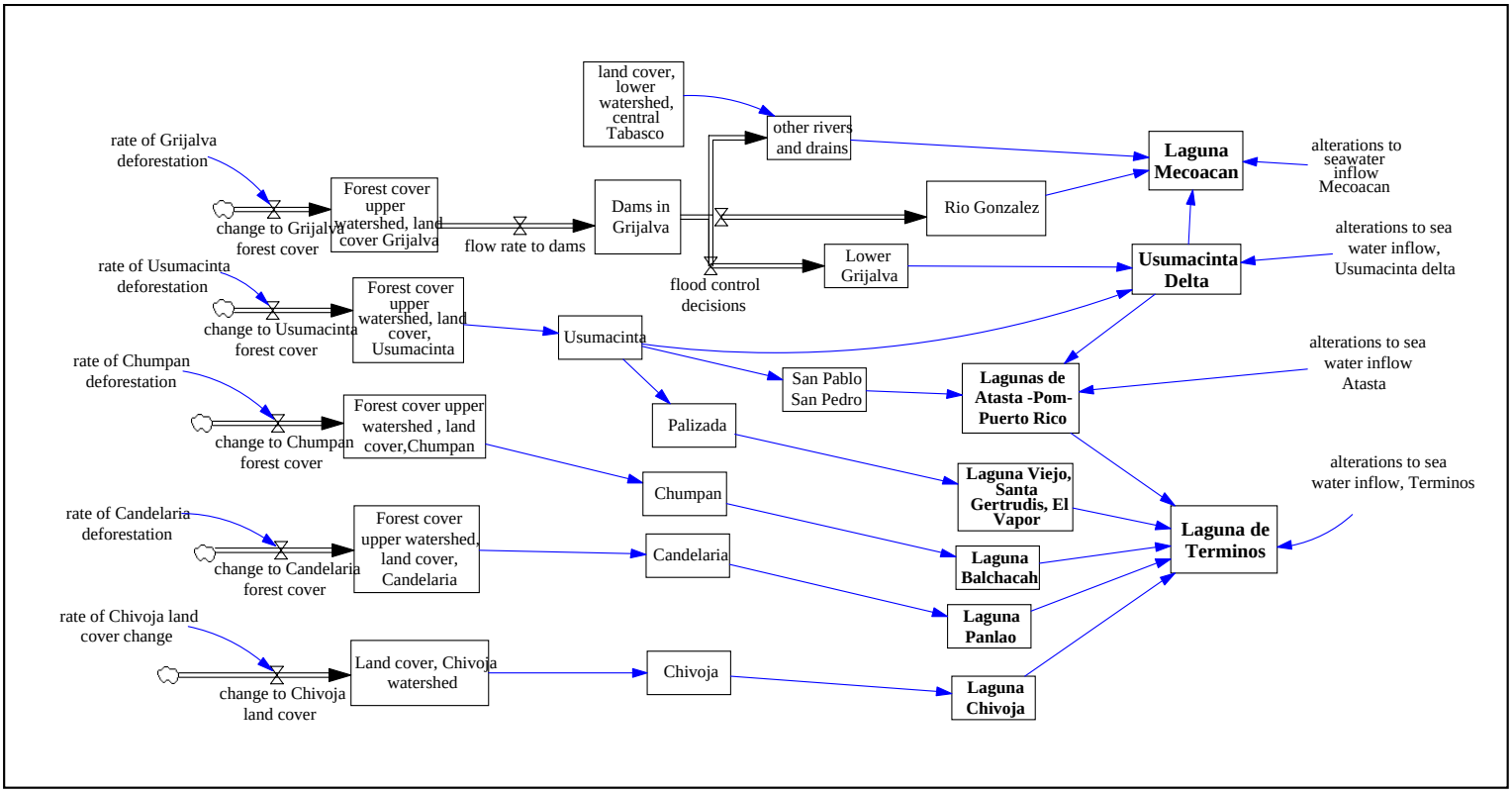
The National Fisheries Commission, CONAPESCA**,** is responsible for fisheries management in Mexico, including restricted areas, seasons, and quotas, as well as development of traditional fisheries and aquaculture. Regulations are set through the mechanism of the National Map (Carta Nacional de Pesca) as well as rules for some species and types of fisheries, most importantly commercial and artisanal fishing. Regional fisheries research stations continue to monitor, study and model the fisheries of Campeche Sound to address questions such as shrimp fishing season opening dates and multiple objective management possibilities.

The Mexican Petroleum company PEMEX is an enormous parastatal corporation, with total revenues of 487 billion Mexican pesos (about 49 billion USD) in 2002. It is engaged in the exploration, development, refinement, export and domestic marketing of the country's oil and gas resources. One of its most important reserves lies just offshore of the Laguna de Terminos in the Gulf of Mexico and production facilities and wells are located in the nearby wetlands and watershed. PEMEX is a major source of foreign exchange as well as funding to the national government. Its responsibility is to comply with federal government regulations and mandates and it also recognizes international quality and performance standards. It is a source of funding for most of the scientific and planning studies that are required to create these regulations, including studies of the coastal region around the Laguna de Terminos.

2. The Defining Characteristics of Laguna de Terminos and Its Watershed

Laguna de Terminos is the largest and the most thoroughly studied estuary in Mexico. It lies at the eastern end of the large and complex Usumacinta River delta that extends approximately 125 km along the southern shore of the Gulf of Mexico (see map below). In the Caribbean basin this delta is second in size to the Mississippi delta and it contains a similar suite of anthropogenic impacts and resource management challenges. These include fragmentation of wetlands by channels cut by the petroleum industry, land subsidence, alterations to the distribution of river waters, deposition of contaminants from the watershed and over-exploitation of fish and shellfish populations.

A schematic of the principal channels for fresh water flow to Terminos Lagoon



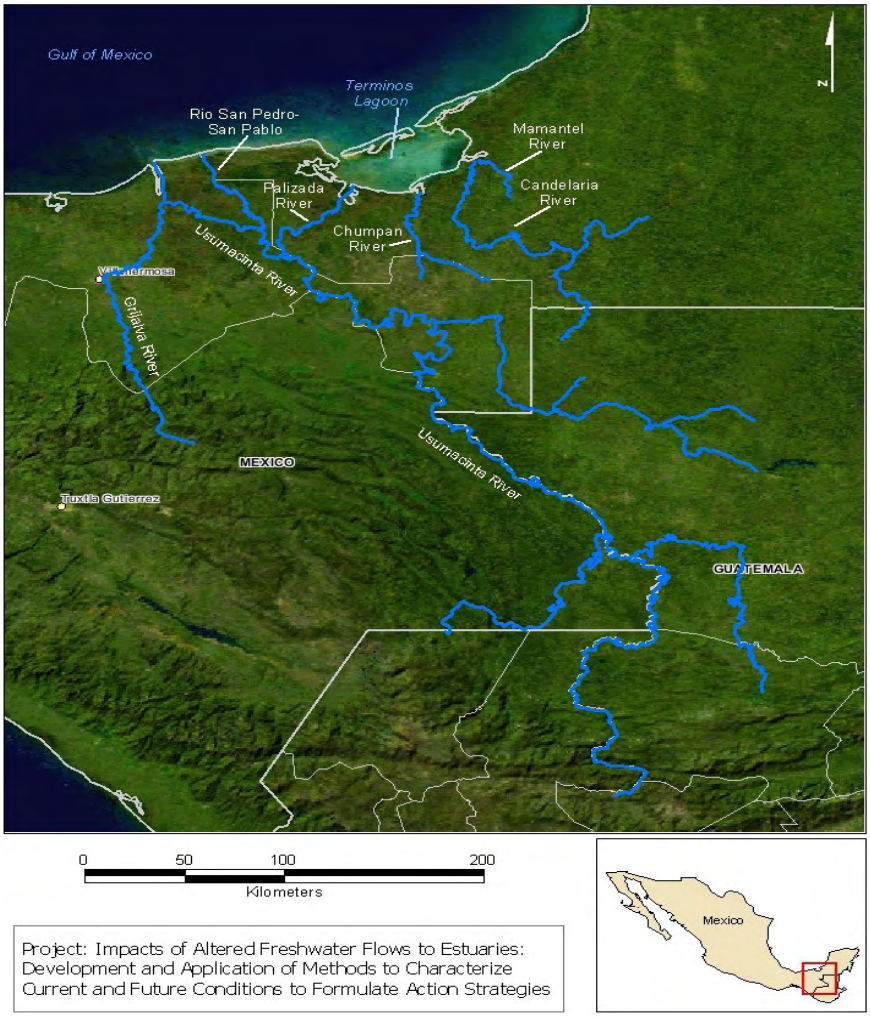
2A. Major Features of the Watershed

Laguna de Terminos receives large volumes of seasonally-varying flows of freshwater from a 49,700 square kilometer watershed that drains portions of the Yucatan Peninsula, the lowlands of Tabasco, and the highlands of Chiapas and Guatemala. The eastern portion of the Terminos watershed in the Yucatan has calcareous soils, low rainfall and no significant surface drainage. To the west and south, a far larger area composed of fluvial soils with high rainfall is drained by the Palizada River, a tributary of the larger Usumacinta River. The Usumacinta-Palizada drains a

mosaic of heavily impacted landscapes that have been transformed from their original dry and wet forests into grazing land and cropland inhabited by a rapidly growing population.

Four river systems contribute freshwater inflows into Laguna de Terminos (see map and schematic diagram below):

- The Candelaria River and the Mamantel flow into the secondary Laguna Panlao on the central southern shore
- The Chumpan River flows into the secondary Balchacah lagoon
- The Palizada River flows into the chain of Viento Este – Vapor Lagoons
- The San Pedro-San Pablo River flow into a chain of secondary lagoons (Pom-Atasta) along the western shore near the Carmen Inlet



The four sub-basins that drain into Laguna de Terminos are dominated by the watershed of the Usumacinta River that drains 80 percent of the total area. The Usumacinta watershed extends into neighboring states of Tabasco and Chiapas, and the highlands of Guatemala. Both the Palizada and the San Pedro-San Pablo Rivers are branches of the Usumacinta. Sixteen percent of the Candelaria watershed also lies in Guatemala. This is an important source of fresh surface water inflow to the eastern portion of the lagoon. Local sources of freshwater, including the discharge of groundwater from the karst topography bordering the lagoon on its eastern side, are likely important in sustaining localized habitats near the discharge points.

Statistics for the rivers discharging into Laguna de Términos.
Source: Laura David, LOICZ. 2000.

	Palizada	Chumpan	Candelaria	Mamantel
Total Drainage Basin area (km^2)	40,000*	2,000	7,160	540
% Gauged area	97	85	81	81
Adjusted Discharges (10^9 m^3/yr)				
Mean	9.08	0.57	2.11	0.16
Minimum	3.63	0.01	0.64	0.07
Maximum	16.11	1.58	5.45	0.78
Average Drainage Basin Temp. (°C)	27	25	27	27
Annual Drainage Basin Rainfall (mm)	1,844	1,602	1,457	1,517

* Includes the entire Usumacinta drainage basin area.

2B. Major Features of the Estuary

Laguna de Terminos is in excellent condition thanks largely to its designation as a Flora and Fauna Reserve in 1994. The lagoon's axis points east to west and it is separated from the Gulf of Mexico by a large barrier spit – Isla del Carmen - which is a major base for both the petroleum industry and a large trawler fleet. The adjoining Gulf, named the Campeche Sound, supports one of Mexico's most productive fisheries.

Laguna de Terminos has been the subject of intense research and monitoring since the mid-1960's and as a result its current condition, and to a lesser degree trends extending back over several decades, are better documented than for any other estuary in Mexico – if not the Caribbean as a whole. Its shallow waters are richly endowed with seagrass beds, oyster reefs and mangrove wetlands. In terms of hydrologic characteristics, the lagoon can be separated into two distinct sub-areas. The western side of the lagoon receives the bulk of the river flow. Here muddy sediments predominate and this is the low-salinity, productive, and well-mixed portion of the lagoon. Its turbid waters and lower salinities do not favor the growth of seagrasses and they are absent from this area of the basin. The central and eastern parts of the lagoon are very shallow with a greater abundance of calcareous sediments. Here seagrass beds are densest off Carmen Island. Oyster reefs are present near the mouths of all the rivers. These are composed principally of the European oyster, *Crassostrea* sp. and extend to depths of 2 meters.

The shoreline of much of the lagoon, including stretches on Carmen Island, contains more than 250,000 hectares of mangroves interconnected by a complex natural system of canals and waterways. The mangroves near the outlet of the Palizada are the largest and most well developed. Some of the trees are over 30m in height.

The productivity of the estuarine system is strongly dependent upon freshwater inputs and annual weather cycles. Along the rivers before they enter the lagoon, there is abundant vegetation, both submerged as well as emergent. The highest levels of primary productivity are associated with this vegetation, which is directly influenced by freshwater inflows from the rivers. Submerged aquatic vegetation (SAV) can be found throughout the fresher portions of the rivers before they enter the lagoon. When precipitation is highest, and in the lower salinity areas of the lagoon, productivity is dominated by the freshwater vegetation; as precipitation diminishes this productivity shifts to the submerged vegetation, namely the sea grasses and mangrove systems, which are found in higher salinity areas.

While there is now no commercial fishing in Laguna de Terminos, many species of commercial value, including two species of penaeid shrimp, are dependent upon the wetlands and lagoons that serve as nursery grounds. These nursery areas are critically important in sustaining fisheries in Campeche Sound, one of the most important fishery grounds in the western central Atlantic. Campeche Sound produces one third of the annual Mexican fishery landings on the Gulf and Caribbean Coasts. The majority of the fish and shellfish species on the adjoining shelf use Laguna de Terminos in some period in their life history.

The most conspicuous fauna of Laguna de Terminos and its associated wetlands are its 49 families and 279 species of birds. The lagoon and its associated wetlands are estimated to be visited by one third of the migratory birds moving along the Mississippi flyway. Many species of reptiles are those associated with the freshwater wetlands of “Pantanos de Centla” on the western border of the Terminos Reserve. Significant populations of morelet crocodile (*Cocodrilus moreletti*) have been reported. The beaches of the lagoon are used as nesting sites by the hawksbill turtle (*Eretmochelys imbricata*) and white turtle (*Chelonia mydas*). Because these are threatened species they are of special concern to Mexican authorities and conservationists.

Freshwater inflows to the lagoon vary with three distinct seasons:

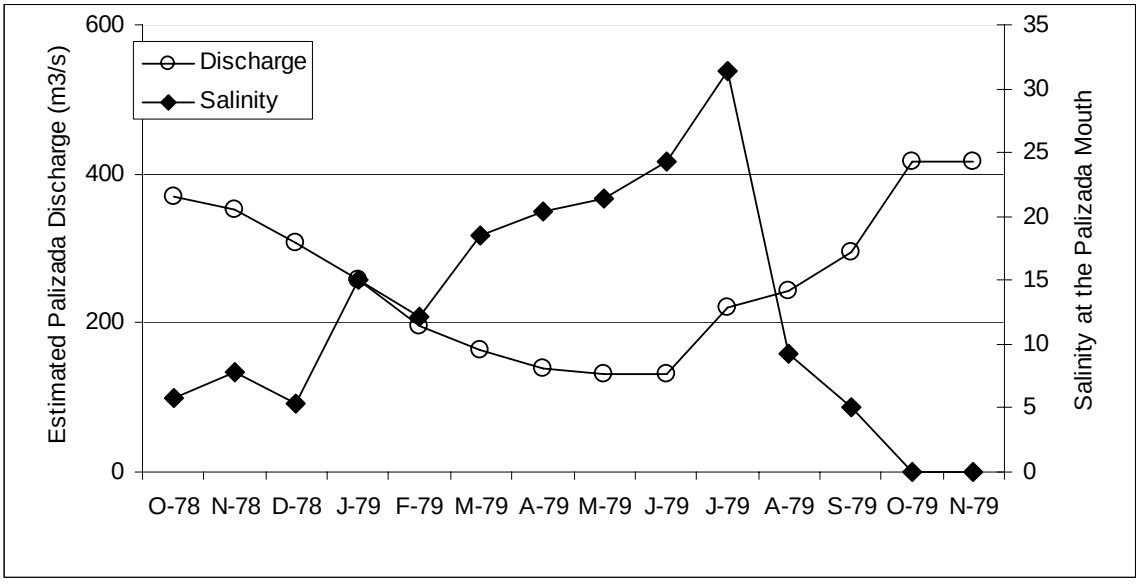
- The first dry season from March through May
- The rainy season from June through September
- The second dry season extending from October through February; this period is marked by intermittent storms (nortes).

Limited inflows from the eastern side of the lagoon result in very high salinities in the eastern two thirds of the lagoon (see water budget below). During the dry season, the eastern half of the lagoon becomes a reverse estuary in which evaporation exceeds freshwater inflows. The majority of the freshwater inflow to Laguna de Terminos enters through the Usumacinta River on the western side of the lagoon and flows into the Gulf through the smaller Carmen inlet. These large river inflows make the western third of the lagoon less saline, more turbid, well mixed and biologically productive than the eastern portion.

Terminos Lagoon Water Budget (cubic meters per second)
Source: Oczkowski, 2005.

	(Discharge (m^3/s)	+ Precipitation (m^3/s)	- (Evaporation (m^3/s)	= Net Inflow (m^3/s)	*Residence Time (days)*
Western 1/3					
Nortes	331	39	26	344	*68*
Dry	92	18	51	59	*254*
Rainy	383	67	49	401	*53*
Eastern 2/3					
Nortes	104	78	51	130	*57*
Dry	29	36	102	-37	
Rainy	120	134	98	156	*33*

The influence of freshwater inflows from the Palizada River on salinity levels in the western portion of the lagoon is quite apparent from the graph below. As flows in the Palizada begin to decline in December-June, the salinity levels near the mouth of the river rise sharply. Over a range of flows of approximately 130-420 cubic meters per second[1] during 1978-79, salinity levels near the mouth of the Palizada River fluctuated from near zero to more than 30 ppm. Hence, it can be assumed that maintaining the seasonal variability of river flows in the Palizada is of great importance to the biological diversity and productivity of the western lagoon, and perhaps the entire system.



[1] Note that these Palizada flows have been estimated using a logarithmic regression developed from the period 1984-1992, when both rivers were being measured.

The tides, freshwater discharge, and local winds are all major forcing mechanisms of circulation and dispersion in the lagoon. A preliminary model of water circulation in the lagoon shows a complex pattern in which the eastern and western areas of Terminos Lagoon largely act independently of each other. The residence times of water are from one to five months as shown in the table above. The blank space in the water table above indicates a negative residence time when the lagoon behaves as a reverse estuary.

The flow and circulation patterns of the Terminos lagoon have important implications for how the freshwater inflows from the rivers affect the ecology of the lagoon. Of the three major rivers draining into the lagoon, the largest, the Palizada, discharges approximately 75% of the total riverine freshwater to the lagoon. This river is at the western end of the lagoon and for most of the year, water discharging from the mouth of this river flows almost directly onto the Campeche shelf. The other two rivers, the Chumpan and Candelaria, discharge proportionally small volumes of water to the lagoon, and while they may have an important effect on the local ecology, particularly in the small sub-lagoons into which they initially drain, their role in supporting the ecological structure of the overall Laguna de Terminos is likely of less significance. The circulation within Laguna de Terminos is thought to be driven primarily by the tidal changes at the two major inlets (Puerto Real & Carmen), as well as the seasonal wind patterns. For most of the year, during the dry and rainy seasons, there is a net east to west flow of water through the lagoon. Then, during the "nortes" season, the wind increases in magnitude and switches direction causing the circulation to reverse direction and become turbulent.

In addition to the surface water streams, there are additional sources of water that may contribute locally-significant amounts of freshwater to the lagoon. In particular, groundwater discharge from the limestone aquifer along the eastern edge of the lagoon may be a very important source of freshwater. Estimates of the amount of freshwater flowing through this aquifer are approximately 1 m^3/m/day (Dr. John Day, personal communication). As this karst landscape constitutes approximately 20,000 meters of lagoon coastline, the amount of freshwater inflow via groundwater may be as much as 20,000 m^3/day (approximately 0.23 m3/sec). Also, according to Dr. Day, the groundwater discharged from the Yucatan Peninsula gets swept into the lagoon by the prevailing currents, increasing the significance of this supply of freshwater. Other sources of freshwater to the lagoon include diffuse overland flow from the lower Usumacinta and Rio San Pedro/San Pablo, which flow toward and through a series of small lagoons and wetlands. Although this freshwater source has not been quantified, there are oyster beds along the western edge of the Lagoon that are not associated with the mouth of any river. Thus, while the role of diffuse flow is unknown, it does seem to be an important source of freshwater to the lagoon. These additional sources of water may mitigate the effects of potential changes in river discharge, provided that changes in land use and land cover do not alter the natural hydrologic processes.

Major Features of Terminos Lagoon

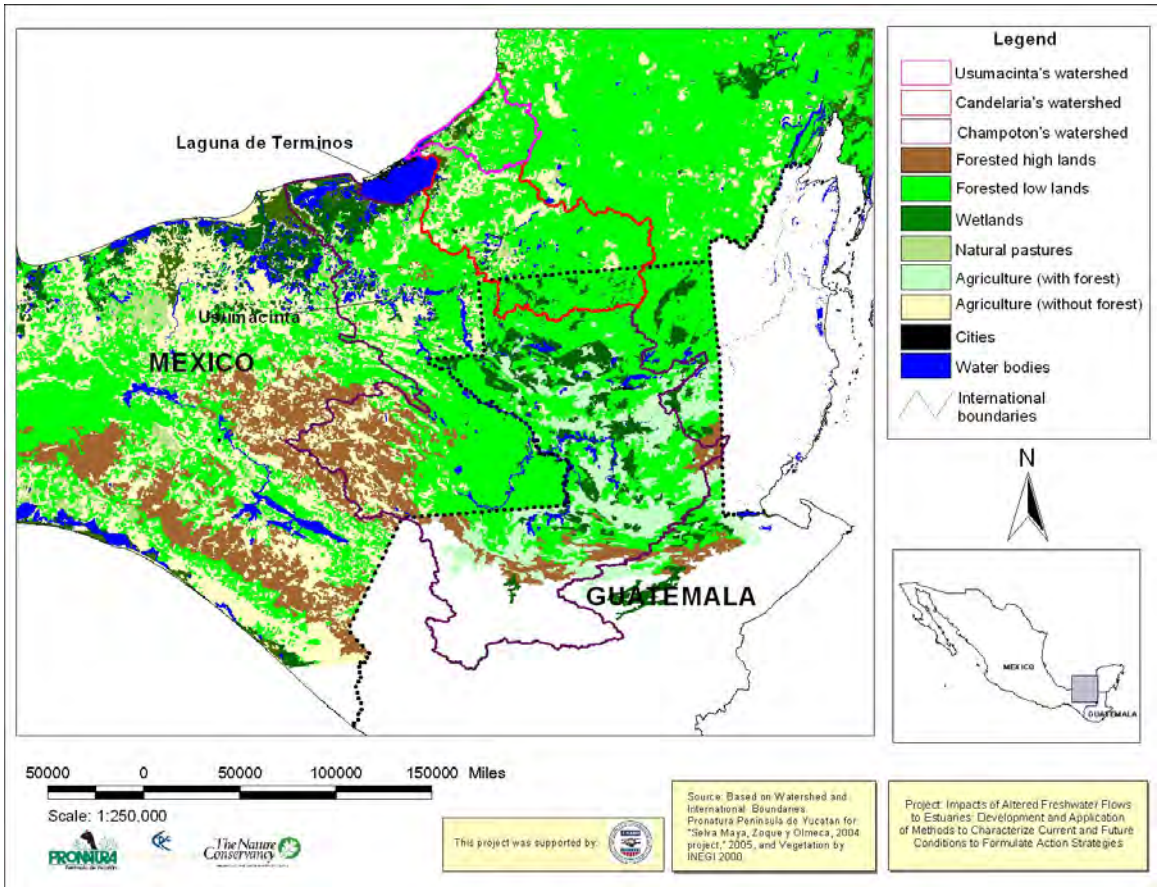
Area km^2	Average depth in meters	Tidal range	Salinity	Residence Time	Major Habitats	Estuarine Activities
1644	3.5	0.5m	5-32 ppt; maximum mean 28.6 in June and lowest mean 9.2ppt in November	75-200 days in the Western third; 50-130 days in the Eastern two thirds	Seagrass beds (298 km^2) Mangroves (2590 km2) Oyster beds	Research and nature tourism; Minor illegal fishing; Minor mangrove cutting

3. Human Uses of the Watershed and Estuary

In the highlands portion of the watershed in Chiapas and Guatemala, the main human uses are subsistence agriculture by a very poor and marginalized population as noted elsewhere (large percentage of indigenous population, low literacy rates, high birth rates, low access to education, health and other basic services, etc.). Some communal forests (ejidos) are being managed for a sustainable harvest, but the majority of forestry resources are being extracted in an unsustainable manner.

In the lowlands (Petén and sections of Chiapas), cattle ranching has been expanding in the past 15 years. Some large protected areas exist in the watershed – mainly Montes Azules Biosphere Reserve in Mexico and Maya Biosphere Reserve/Sierra del Lacandon National Park in Guatemala – and other smaller areas complement the mosaic of land dedicated to conservation. Nature and archeology-based tourism is a growing industry in the watershed.

Areas of the region (both in Guatemala and Mexico) have been under civil unrest for many years, hence, governance issues and ownership/responsibility for the management of natural resources is still precarious.



Natural Resource distribution within the watersheds of the Terminos Lagoon.

3A. How Have Human Activities in the Watershed Evolved over Time?

The Laguna de Terminos has long been important for trade and was a military outpost of the Mayans and Chontals well before the colonial era. There are numerous archeological sites of importance on the coast and along the tributary rivers. Since the Spanish conquest there have been three distinct periods in the exploitation of the region's abundant natural resources.

Palo de Tinte boom and bust period -- The "palo de tinte**"** (*Haematoxilum campechianum)* is a thorny tree used to produce ink. It was a valuable export from the early colonial period into the 20th century. The trees were logged throughout much of the watershed. Chicle (gum tree) and other tropical timbers were also extracted from the interior and shipped from the port of Carmen. By the first half of the 20th century, the timber resources had been exhausted, leading to dramatic economic decline in the logging industry.

Fisheries boom and bust period – Until the 1940s very little commercial fishing existed in the Laguna de Terminos vicinity. Local fishermen would sell their products in local markets, and virtually all seafood was consumed locally. Beginning in 1948, the local population began to

discover the potential of industrial-scale commercial shrimp harvesting. At the request of the federal government, a number of foreign-owned processing plants were established in Ciudad del Carmen.

A succession of shrimp stocks were exploited: the white, brown and the "camaron gigante" or giant shrimp. In 1950, 4035 tons of shrimp were harvested by more than 200 boats working out of Ciudad del Carmen. The harvest grew to more than 6,000 tons harvested by more than 400 boats in 1980. However, the first signs of over-harvest had been apparent in the mid-1940's as the white shrimp population declined abruptly. The brown shrimp (*Penaues aztecus*), became the target. By the mid-1990's the Carmen shrimp harvest had declined to less than 5,000 tons, and by 2003 it had declined to less than 3,000 tons. With declining shrimp harvests, fishermen began to extract a growing variety of other species, principally fish. In 2002 the total landing recorded for Carmen were 20,500 tons, of which shrimp, crabs (jaiba) and largemouth bass (robalo) made up more than one third.

Petroleum extraction -- The era of petroleum development began in the 1970s when Petroleos Mexicanos, or PEMEX, a state-owned enterprise, was created to develop, refine, market and export Mexican oil. The environmental damage and social conflicts generated in the early decades of its development included the dramatic growth of Ciudad de Carmen. A response to these pressures was the declaration of the Terminos Reserve and the Centla Biosphere Reserves in the early 1990s. Oil exploration continues in Campeche Sound and in Centla. A road is planned through the lagoon's wetlands. Oil and gas supplies are expected to last for no more than an additional two or three decades, at which point the regional economy of the Terminos will likely enter a new era.

3B. Current Management Issues within the Terminos Reserve

Human activities in the vicinity of Laguna de Terminos prior to Reserve designation were largely the same as current ones: fishing, low-scale agriculture and cattle ranching. However, there have been recent changes in the scale of the activity, with cattle ranching areas increasing along the southern end of the lagoon (forest being converted to cattle operations). Only in the "highly restricted" areas of the Reserve have economic activities decreased. Additionally, new activities have appeared in the last decade, such as aquaculture and very-small scale tourism. Also, more "services" are spreading in Carmen City related to its growth (construction, transportation, etc.).

The marine resources inside the Flora and Fauna Reserve are in large measure protected, but some illegal fishing still takes place. Fishermen realize that their economic activity (productive fishing grounds) depends upon the lagoon, but they have not yet adequately adjusted their behavior or activities to abide with conservation regulations (fishing seasons, etc.). Most fishing and small-scale aquaculture is within the sub-lagoons in the western portion, centering around the Atasta Peninsula.

Rapid development and population growth on Isla del Carmen vastly outstrips the ability of local institutions to address the multiple problems of an under-serviced urban area. Water quality around the western part of the island is threatened by the inadequately treated wastewater from the City of Carmen. Oil spills from offshore wells as well as operations inside the reserve remain a problem as well.

Mangrove forest stands throughout the Terminos area are intact but also are impacted by some cutting as well as continuing sedimentation to the inner lagoons. Mangroves are also affected by having channels cut through them, water flow blocked by highways or even fishing gear that traps fish, but also sediment and debris. This affects circulation and sedimentation in the several small lagoons around the edges of the Laguna de Terminos. Shore areas at the eastern mouth of the lagoon are eroding. Poor shore uses and "shore protection" devices are in some instances cutting off of circulation to mangrove stands.

The management issues that place the conservation goals of the Reserve in a larger context are as follows:

1. *Extreme poverty* is found throughout the watershed. The Atasta peninsula, which forms the western side of Laguna de Terminos, has had a long history of conflicts between local groups, such as the Movement of Fishers and Farmers of the Peninsula of Atasta, and the petroleum industry. There is a tradition of blockading roads to get "compensation" through public works, usually funded by PEMEX. A high proportion of the population living in the municipality of Carmen is also very poor. Eighty percent of the villages in the municipalities abutting the lagoon and 51% of the population outside the city live in areas with the highest rankings for “marginalization” (4 and 5 out of a scale of 1-5). Settlements by and large lack potable water, sewage, school facilities, and health services. Sixty–three percent of these villages and 32% of the total population in Palizada endure similar conditions.[2]

2. *Leaks and breaks in the extensive network of oil pipelines* that crisscross the lagoon and its surrounding wetlands are another chronic problem.

3. Domestic sewage, wastewater and agricultural runoff all produce localized *water pollution*, particularly in the vicinity of Carmen.

4. *Land use within the Centla Reserve* is another concern. Here 23% of the land is privately owned and used for agriculture and cattle raising. Rice production appears to have ceased in recent years. The managers of the Reserve are experimenting with aquaculture and animal husbandry projects designed to reduce exploitation pressures on native species.

5. *The construction of bridges* linking both ends of Carmen Island to the mainland has increased access and pressures on the wetlands. The improved access has the potential of attracting ecotourism but so far this has not materialized.

6. *Minor illegal fishing and mangrove cutting* occurs within the lagoon and on its margins.

7. *Continuing road construction*, including most recently a connection between Palizada and Atasta that will provide access to an as-yet untouched area of wetlands. Such infrastructure development (bridges and roads) can impact both the condition of the lagoon as well as the freshwater inflows in the lower parts of the contributing watersheds. This infrastructure has the potential to restrict flows both into and out of the lagoon. A proposed bridge in the

[2] SEDESOL, Campeche. Data for localities is from 1995, calculations by the author.

vicinity of Ciudad del Carmen could cause restrictions in the movement of water into and out of the lagoon from waters in the Gulf of Mexico, as well as the freshwaters flowing through the Carmen inlet. The roads in the coastal plain may also potentially restrict the sheet flow currently draining into the wetlands.

4. Potential Future Threats to Freshwater Inflows and Estuary Health

4A. Future impacts from changes in freshwater inflows

Because the Palizada River delivers three-fourths of the annual volume of freshwater inflow to Laguna de Terminos, the project team has concentrated its investigation of hydrologic alteration on the Usumacinta-Palizada system. While many localized changes to water flows and landscape cover in the vicinity of the lagoon could affect portions of the lagoon (as discussed below), the overall ecological structure and function of the lagoon is not likely to be impacted unless the inflow of water from the Palizada is substantially altered.

A major hydroelectric project, the Boca del Cerro, has been proposed for the Upper Usumacinta watershed in a location upstream of the Palizada distributary. It has been repeatedly put forward and deferred in the past two decades. According to the Third Millenium Project[3]:

> "The Boca del Cerro Project, would be located 9.5 kilometers southwest of Tenosique, Tabasco. It would have a 130 meters-high dam creating an artificial lake formed by the 19,550-million cubic meter reservoir. The electrical generating power the facility would be 4,200kw**.** This would be 67% of hydropower produced by Mexico and could replace 29 million barrels of oil.

The project's advocates envision the dam as the catalyst for industrial, commercial, and tourism development that would bring multiple social and economic benefits including employment, housing, agriculture and cattle raising, navigation, roads, environmental and ecology protection. In 2001, Mexico revived the Usumacinta hydroelectric project, but when met with much local opposition, Guatemala withdrew its agreement to participate. The Presidents of both Mexico and Guatemala have recently stated that the dam as originally proposed is "a dead issue."

However, Mexico may attempt to build a much smaller dam on its own (for reference see http://www.inforpressca.com/CAR/homes/h2942.pdf). This dam would be a 'run-of-river' facility. Some reports say that this will involve a 40 m high dam and others claim only 18 m high (the International Commission on Large Dams defines as a large dam any dam that is higher than 15 m). Government officials also insist that flooding would be limited to those areas already inundated during the rainy season. As Guatemala does not think that its territory will be affected, it appears to be comfortable with this project. However, Mexico cannot legally construct this dam without Guatemala's approval according to a 1961 agreement, where both countries must agree on such projects involving certain bi-national waters (including the Usumacinta), and Guatemala has not yet seen any official plans. The Mexican government apparently does not plan to take any further action on this new proposal until 2011-2012.

[3] Frias, 2003.

Several regional and international organizations are aware of the project and are likely to oppose it if it is reactivated. At this time all indications are that this project has a very low likelihood of implementation. The region where the dam is proposed is in the process of becoming declared as a State Natural Protected Area, encompassing approximately 48,000 hectares, and a management plan for this protected area will be published during the upcoming year. Even if the smaller dam project were to be developed by Mexico, it is highly unlikely that freshwater inflows to Laguna de Terminos would be significantly impacted. A run-of-the-river facility will have very little storage capacity with which to alter the volume or timing of river flows. For the most part, water would simply pass through the hydro-electric turbines with little alteration in its flow rate.

Another piece of the original Boca del Cerro project, the Balancan diversion canal, would likely become infeasible under this new plan. The Balancan canal would transfer flood waters in the vicinity of the city of Villahermosato into the Usumacinta River and possibly directly into Laguna de Terminos. The dam and diversion canal would transfer sufficient flows to generate an additional 1,250 million kilowatt-hours from a low-head hydropower plant. The Balancan canal is linked to an extensive program of flood control in the Usumacinta and Grijalva rivers in the state of Tabasco. The proposal claims that the northern and eastern regions of Tabasco, and the southwest of Campeche would both see significant economic benefits, and permit the construction of much needed sewerage treatment facilities, increase navigation and transportation in the river and allow for draining over one million hectares of lands for agriculture and cattle raising. The impacts on the lagoons to the west of Terminos are expected to be severe and are reason for major controversy in this region. With the postponement or abandonment of the original Boca del Cerro project, development of the Balancan canal now appears to be highly unlikely. However, this is an issue that should be continually monitored by park managers and other stakeholders in the Laguna de Terminos area.

Based on this information, the project team has concluded that there does not appear to be an imminent threat to the freshwater inflows that most strongly influence the ecological structure and function of Laguna de Terminos at this time.

The National Water Commission Region XII management program has identified the following additional issues of concern in the watersheds feeding Laguna de Terminos:

- Opening of land for agriculture
- Logging of old forests
- Infrastructure construction
- Use of agrochemicals
- Petroleum industry impacts including frequent oil spills and breaks in pipelines

Although a number of land and water management issues have been identified in the watersheds feeding Laguna de Terminos, the available information indicates that changes in freshwater inflows to the estuary are not a significant threat to the ecological function and integrity of the system at this time. Other factors that limit the potential risk of changes in freshwater flows to the estuary are the population and land use trends in the surrounding communities and greater watershed. At the watershed scale, much of the original land cover has already been converted to agriculture, grazing or urban uses, but it is not anticipated that there will be additional large-

scale changes unless population dynamics in the area change substantially. At the local scale, Laguna de Terminos and adjacent shorelands are fully incorporated into a Natural Flora and Fauna Reserve. As such, the land use activities and potential land use changes in the immediate vicinity of the estuary are limited. In addition, relatively few people live in the areas surrounding the lagoon and those that do typically practice small-scale agriculture, subsistence fishing and cattle ranching. The two municipalities surrounding the lagoon, Carmen and Palizada, had a combined population of 180,477 in 2000 and there is currently no trend indicating dramatic increases in population in the region. Despite this current situation, there is the potential for a new road to be built through this area which could change these forecasts. This road could potentially facilitate the movement of people to the region, creating land use changes with unforeseen effects on the water flows through this relatively intact area.

The dynamic estuarine system of the Terminos lagoon has critical and keystone biological processes that could be susceptible to changes in freshwater inflows. Processes associated with primary production, nutrient biochemical reactions and sediment are governed by the interaction of fresh and salt water. Changes in this balance could occur, and localized changes are likely already occurring to some degree, due to road building, land use changes and general water use associated with a growing population. These aspects are not easily measured, but their impacts are cumulative. Therefore, the potential for long-term changes to the lagoon due to changes in freshwater flows cannot be completely dismissed.

4B. Other factors affecting water quantity and quality in the estuary

Several other localized activities may pose risks to water quantity and quality in Laguna de Terminos. The majority of the people living around the lagoon are in Ciudad de Carmen on the Island of Carmen. Waste discharge and other forms of pollution from the City of Carmen affect water quality in the estuary. Wastewater from petrochemical and other PEMEX operations, for example a nitrogen plant, has been cited as a potential source of water quality alteration in the lagoon. A factor cited as potential mitigation for the negative effects emanating from these operations (including Ciudad del Carmen) is that prevailing currents within Laguna de Terminos take most of the discharge directly towards the Boca del Carmen outlet, where it is diluted in the Campeche Sound and Gulf of Mexico. However, during the Nortes, and at times the rainy season, the waters of the lagoon are well mixed, and this pollution may enter and remain within the lagoon. If this happens regularly, and the residence times in the lagoon increase due to decreases in freshwater inflows, pollutants may begin to accumulate in the sediments, affecting the biological components of the system. This accumulation may eventually limit the viability of the system to function as an estuarine habitat and nursery ground, with associated effects on biodiversity.

Dredging of canals for navigation and petroleum exploration has the potential to interrupt the diffuse overland flow from the lower Usumacinta and Rio San Pedro/San Pablo into the Terminos lagoon, which could have a localized effect on important biodiversity such as the oyster beds. Road construction, in particular a proposed road from Palizada to Atasta as was mentioned above, has the potential to have similar effects on overland flow, sediment deposition, and biotic distributions and abundances. In addition, oil drilling and associated canals and dredging operations in the delta may be affecting sedimentation patterns and contributing to

subsidence, which coupled with potential sea level rises in response to climate change, could significantly affect the distribution and survival of biological communities within the estuary.

5. Major Stakeholders and Their Interests

The International Bio-Diversity Community and the Mexican conservation and ecosystem science research community. The major international NGOs, including The Nature Conservancy, World Wildlife and Conservation International, and their Mexican counterparts, see Laguna de Terminos and the Centla Biosphere Reserve as internationally significant wetland ecosystems, which is reflected in their inclusion in the RAMSAR Convention on Wetlands List. As a result the coastal area figures prominently in the strategic plans of all three. The Nature Conservancy includes them as part of their Yucatan Coastal Wetlands focus area. Conservation International designates them as a "key biodiversity area" within its Meso-American Hotspot.

The upper watersheds of the Candelaria and the Grijalva-Usumacinta River systems are within the Meso-American Biological Corridor. All three of the international NGOs feature the Maya Forest and its associated parks and biosphere reserves in their priority lists. Each works with local Mexican and Guatemalan partners, as well as corresponding government agencies to foster the legal protection, site conservation planning and building implementation capacity to achieve permanent protection.

The reason these areas are of such concern is the fear of both large-scale development projects and continuing encroachment and destruction from ongoing local exploitation of land and forests. The Plan Puebla-Panama program to integrate the economies of Mexico and Central America is seen as a threat by conservation groups and some human rights and social activists inside and outside of the region. Their concern is that the development plan will displace poor communities in the upland areas, and accelerate the construction of highways and electrification infrastructure that will bring forms of modernization that are not perceived as beneficial to biodiversity conservation or local groups. Local land use practices, market forces, poor enforcement and development investments in the wetlands and watersheds also are also perceived as threats by these institutions.

Petroleos Mexicanos, PEMEX. PEMEX is under considerable pressure to continue contributing to the national government budget and provide employment and investment returns to the Mexican economy. Its investments in the Campeche Sound just off the coast of the Centla and Terminos reserves represent more than 80 per cent of the crude oil and 30 per cent of the natural gas produced by Mexico. PEMEX intends to establish 17 offshore wells and an extensive underwater pipeline system in the Campeche shelf area. PEMEX's land based facilities are inside and adjacent to the Centla biosphere reserve. It has recently publicly stated that it has no plans to open up new land based exploration and development wells inside the reserve, but is committed to fully exploiting the sites it currently has in operation. Some of these wells are in or near the designed Nucleus Zones of the Centla Reserve. A principle reason for establishing the Terminos Reserve was to prevent PEMEX from further exploration and development operations in the lagoon and its associated wetlands.

PEMEX is facing a continuing need to prevent chronic oil spills from these pipelines and facilities as well as remediate areas damaged by the existing installations and past spills. It faces a continuing series of confrontations with villagers, fishers and others throughout the areas, which it seeks to resolve in several forms. In the past these claims were addressed through periodic payments and arrangements with individual groups or communities, which it found has fostered further cycles of public outcry and demand for compensations. More recently PEMEX has provided payments to the coastal states including Campeche and Tabasco and is considering the formation of a Fund for the Gulf of Mexico Fisheries that would finance fisheries development projects. It also funds restoration and tourism development projects in the Centla area.

PEMEX is also concerned about the physical security of its growing network and multi-billion dollar offshore investment. It maintains a sophisticated tracking and response system for all boats approaching its water and wetland based facilities, including fishers and other vessels operated by local people.

Fishers operating in Campeche Sound. While the collapse of the shrimp fishery in the Sound can be attributed to long term environmental changes as well as overfishing and poor management, fishers are focusing on the growing access restrictions in the Campeche Sound oil and gas fields. The memory of one of the world's largest oil spills, the Ixtop I event of 1979 still persists. There are chronic spills along the coast. Fishers want compensation for loss of access to fishing grounds and chafe at the tightening security measures set up by PEMEX to protect its rigs and pipelines from physical damage. These and other grievances lead the fishers to engage in highway blockades near the land-based oil and gas processing facilities as well as actions against PEMEX personnel traveling in the area.

Communities in extreme poverty living around the margins of the lagoons. These communities have very little access to basic services, potable water and drainage. Palizada town inhabitants are strongly advocating for the construction of the Atasta-Palizada road, since they see that their isolation or difficult access is limiting their economic development. Local villages continue to seek compensation from PEMEX for past and ongoing environmental damage to coastal wetlands, waterways and lagoons from construction of facilities, pipelines, infrastructure and spills which displaced residents and degraded fisheries habitat. They also want funds targeted for local economic and community development, arguing for a larger share of benefits from the payments by PEMEX to national and state authorities. Although not in "extreme poverty," the cattle ranchers to the south of the lagoon are advocating for their fair share of "socio-economic development" as well.

Potential beneficiaries of the dam and water diversion canal. The water resources, timber and agricultural production capability of the combined watersheds in this poor and underdeveloped region of southern Mexico are affected by deforestation, especially of precious woods, and poorly managed and inefficient agriculture. These produce soil erosion, and escalating social conflict. This region is at the heart of the Mexico segment of Plan Puebla-Panama. Political leaders, promoters and investors see benefits to themselves and the very poor local populations flowing from a large scale development program that would bring improved transportation, communication, agriculture, water resources, power generation and flood control.

The residents, business leaders and public officials in central and coastal areas of Tabasco are more concerned about the protection of the increasingly vulnerable City of Villahermosa. They are focused on protecting the growing settled areas and economic infrastructure from what they perceive to be increasingly destructive annual, and periodically extreme, flooding.

The staff and water commissions for Regions XI (Tabasco and Chiapas) and XII (Campeche, Yucatan and Quintana Roo). The Region XI Commission was formed in 2000 and the Commission for Region XII the year before. These fledgling institutions in Southern Mexico have not yet focused on river basin or aquifer management. The Grijalva-Usumacinta and Candelaria watersheds are split between two nationally designated Water Regions. The Water Resource Program for Region XI recognizes the issue of fresh water flows to estuaries in terms of quantity and quality, specifically for the wetland lagoon system La Encrucijada along the central coast of Chiapas on the Pacific coast. However, little analysis of this issue has been made so far. The Program for Region XII does not specifically mention estuaries and lagoons. The Watershed Councils have so far have focused on specific concerns such as infrastructure works for supply and flood control, decentralization of water allocation decisions and the functioning of irrigation districts.

The municipality of Carmen and the City of Carmen. The Municipality, which includes the city and the surrounding rural areas around the Terminos Lagoon, has grown dramatically since the offshore oil development boom began in the 1980s. It is now facing a number of serious problems. These include attempting to cope with the excesses of immigration and unguided urban growth, a shortage of buildable land that puts pressure on flood prone areas and mangroves, serious deficiencies in infrastructure including poor potable water supply, and an inadequate wastewater and solid waste collection and treatment systems. It is among 32 large cities recognized nationally as important focal points for environmental planning. The City also seeks to diversify its economy in anticipation of a post-oil boom downturn. It is frustrated in its attempt to address such a broad array of urban and rural development challenges with financial resources, given the generation of oil wealth just off its coast that feeds the central Mexican financial system with low return to the region.

6. The Current Governance System for the Lagoon and the Watershed

The National Parks Commission, CONANP, is responsible for all Mexican parks and reserves. The Laguna de Terminos was declared a federally designated Flora and Fauna reserve ("Area de Protección de Flora y Fauna") in 1994. The Reserve boundaries incorporate portions of the lower watersheds of the Candelaria, Chumpan and Palizada, and abut the biosphere reserve Pantanos de Centla that had been created in 1992. Both the Reserves, an area of 1,007,723 hectares, are administered by a five person team from the National Parks Commission.

The management plan for the Terminos Reserve features a detailed zoning map that assigns lands within the Reserve to five categories of use ranging from “highly restricted” to “urban”. The plan calls upon numerous federal, state and non-governmental actors to contribute to the implementation of the 24 elements of the management plan. The staff assigned to develop the management plan for the Terminos Reserve worked with a Consultative Council that drew

together a diversity of interests and academics and initially was established to provide a greater balance of local and state interests in reserve management. A subcommittee was established to specifically address oil development issues. The Council began with great promise but never managed to operate with transparency or focus. Both PEMEX and the federal government subsequently reduced their support to the council and its members and set up other mechanisms for supporting local development projects. The Council was disbanded when a new Park Director was appointed in 2000.

A review of the Terminos Reserve plan by Currie-Alder (2001) highlights two weaknesses in terms of watershed and freshwater flow issues. The first is the plan's sparse consideration of the potential impacts of changes to freshwater inflows to the lagoon. The second is the absence of a mechanism for engaging stakeholders on issues of local concern or on the more far ranging impacts of flood control, hydropower generation and continuing shifts in land use. This critique notes that the Consultative Committee was marked by a strong concern for the Reserve and a sense of ownership for the plan. This report implies that it should not have been disbanded.

7. Proposed Future Activities

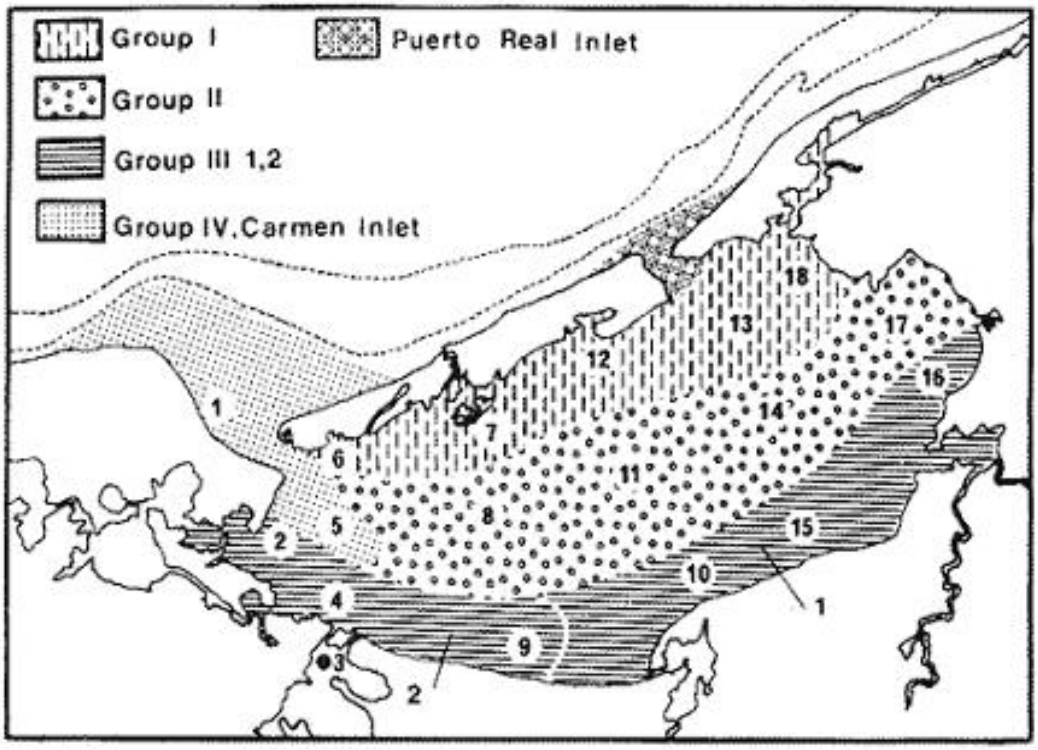
As stated above, it is the conclusion of the project team that the essential freshwater inflows from the Palizada system do not appear to be in jeopardy from any major impoundments (dams) at this time. However, we do recommend that a fairly simple and straightforward monitoring program be put into place that will enable park managers and other stakeholders to track any future significant freshwater inflow changes into the lagoon, as well as to better understand the effects of localized impacts to the estuary. Such monitoring should be designed to also improve scientific understanding of the bio-physical relationships in the lagoon. To this end, the project team contracted with Dr. AlejandroYáñez-Arancibia and Dr. John Day of Louisiana State University, who have been working in Laguna de Terminos for more than a decade, to develop suggestions for such a long-term monitoring program. Through their analysis, we have identified a potential monitoring program for Laguna de Terminos to advance our scientific understanding of the estuary and to track any potential changes due to land and water management activities. The project team will hold future future discussions with park managers and other stakeholders about the proposed monitoring program, the feasibility of implementing it, and specific monitoring methods and protocols.

7A. Proposed Monitoring Plan

Sampling sites were selected based on the functional dynamics of Terminos Lagoon and the five subsystems of habitats described by Yáñez-Arancibia & Day, 1980 and Yáñez-Arancibia & Day, 2005 and shown in the figure, below.

- Group I, the inner littoral of El Carmen Island, located on the North side of the lagoon, presents a persistent marine influence which keeps salinity and transparency levels high.
- Group II, the central basin, considered a transition area between the marine conditions of the Northeast and the brackish areas of the south and west sides, has a gradient going from marine to fresh water.

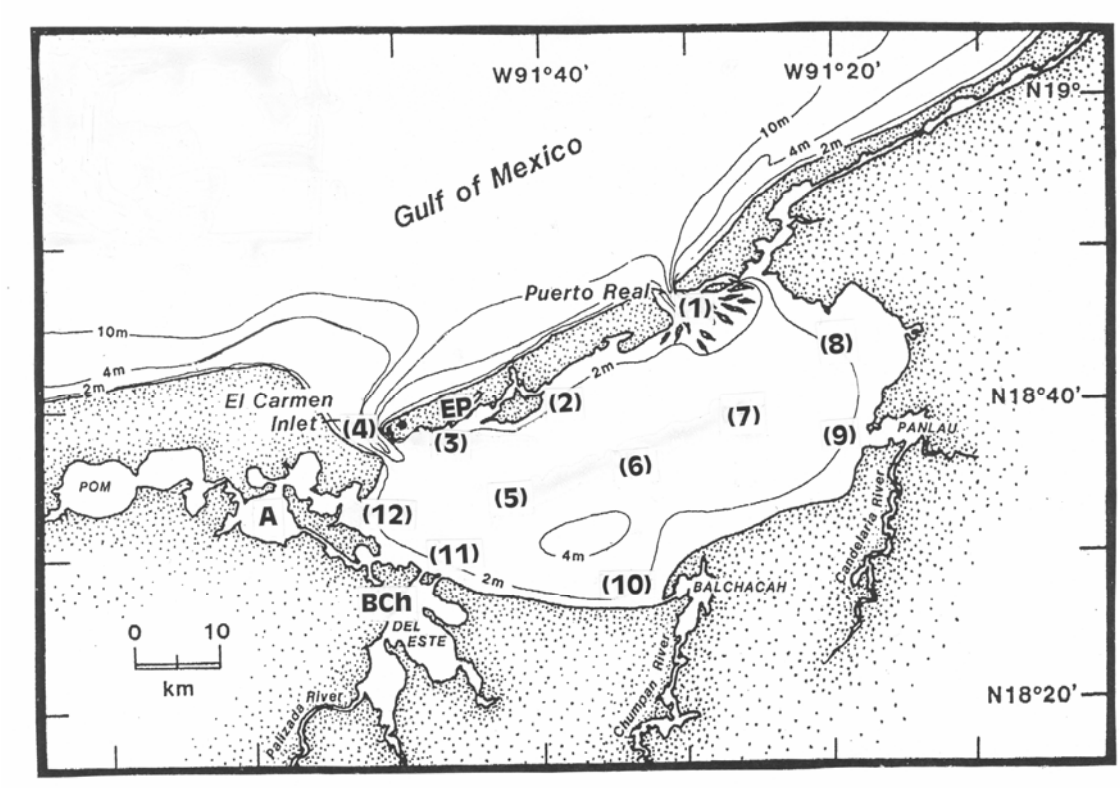
- Group III, the fluvial-lagoon systems found on the South and West sides of the lagoon, has low salinity and transparency levels.
- Group IV, Boca del Carmen, found on the west side of the lagoon, receives fresh water influence from the adjacent fluvial-lagoon systems, marine waters from the Gulf of Mexico, and brackish lagoon waters.
- Group V, Boca del Puerto Real, found to the East of the lagoon, has a predominantly marine influence with high salinity levels.



The sampling sites cover the two Inlets, the Inner littoral of Carmen Island, the Central Basin, and the Fluvial-lagoon system inlets to the lagoon:

Site 1 = Puerto Real Inlet
Site 2 = Inner Littoral Carmen Island (Isla Pajaros)
Site 3 = Estero Pargo Inlet
Site 4 = Carmen Inlet
Site 5 = Central Basin (western)
Site 6 = Central Basin (mid western)
Site 7 = Central Basin (mid eastern)
Site 8 = Central basin (eastern)
Site 9 = Fluvial-lagoon (Candelaria river inlet)
Site 10 = Fluvial-lagoon (Chumpan river inlet)
Site 11 = Fluvial-lagoon (Palizada river inlet)
Site 12 = Fluvial-lagoon (Atasta inlet)
Site EP = Estero Pardo
Site BCH = Boca Chica
Site A = Atasta

The following map shows the location of the recommending sampling sites.



Sample parameters, locations and frequency of sampling:

Single site within estuary:

1. Water level with tide gauges, air temperature, rainfall and cloud cover; continuous measurements
2. Water column depth, tidal state, current speed and direction, water temperature, pH, and conductivity; monthly

Sites 1-12, monthly measurements:

1. Salinity, surface and bottom
2. Water transparency, Sechi depth, and suspended particulate material
3. Chlorophyll-*a* surface concentration
4. Nutrient concentrations at the surface
5. Oxygen concentration at surface and bottom
6. Coliform bacteria at the surface and in *Crassotrea virginica* reefs
7. Water temperature, pH, and conductivity

Thalassia testudinum (seagrass) beds, sites 1, 2 and 3:

1. Seagrass biomass, monthly or three time per year, in February (end of 'nortes' season), May (end of dry season), and October (the highest river discharge at the end of the rainy season)
2. Distribution of seagrasses, monitored using aerial photographs, seasonally as described above.

Mangrove habitats, sites Estero Pardo, Boca Chica and Atasta:

1. Mangrove litterfall, monthly.
2. Mangrove stem growth, yearly.
3. Soil accretion, yearly.
4. Sediment elevation, yearly.
5. Water column depth inside mangrove swamps, continuous or monthly

Data interpretation and application:

The monitoring data can be used to interpret the impacts of changes in water quantity and quality on the productivity and health of Laguna de Terminos. River discharge provides freshwater which reduces salinity, nutrients which stimulate productivity, and suspended sediments that reduce light penetration in the water column. Measurements of mangrove litterfall and stem growth, and soil salinity can be correlated with mean lagoon salinity, climate data, and river discharge to determine the impact of changes in water quantity and quality on mangrove productivity. Measurements of seagrass biomass and aerial extent, and chlorophyll are indicators of seagrass productivity. Correlation of these data with nutrients, water column transparency, river discharge, and other factors can help understand the impact of changes in freshwater inputs.

Data on rainfall, evaporation, groundwater input and river discharge can be used to calculate annual water budgets. Over time, this will provide data on inter-annual variability in the water budget and longer term trends in the components of the water budget. The water budget information can also be used to calculate inputs of nutrients and suspended sediments, as well as residence times in the lagoon.

Parameters such as nutrient concentrations, chlorophyll, turbidity, and coliform bacteria can serve as indicators of water quality. Water quality indices could be developed from these parameters to identify status and trends of water quality and lagoon health. These could then be compared with changes in the quality and quantity of freshwater input to determine the impact of these changes on the lagoon. Measurements of soil accretion, sediment elevation and water column depth in mangrove sites can provide information on the impacts of road construction and canal dredging on these important habitats.

Taken together, the above information will allow evaluation of the long-term sustainability of the Laguna de Terminos ecosystem.

References

Amezcua-Linares, Felipe and A. Yanez-Arancibia (1980) Ecologia de los sistemas fluvio-lagunares asociados a la laguna de terminos. El habitat y estructura de las comunidades de peces. An. Centro Cienc. del Mar Y Limnol. Univ. Nal. Auton. Mexico, 7(1): 69-118.

Castilla, I. 2001. La Península de Yucatán: Un Avance en el Manejo Integral de Cuencas por la CNA. XI Congreso Nacional de Irrigación. Guanajuato, México. 19-21 Septiembre.

Comisión Nacional de Agua. 2003. Programa Hidráulico Regional 2002-2006 Región XI Frontera Sur.

Comisión Nacional de Agua. 2003. Programa Hidráulico Regional 2002-2006 Región XII Península de Yucatán.

Comisión Nacional de Agua. 2003. Programa Nacional Hidráulico 2001-2006.

CONANP, Comisión Nacional de Areas Protegidas, SEMARNAT. 1997 Programa de manejo del Área de Protección de Flora y Fauna "Laguna de Términos"

Currie-Alder, Bruce. 2001. Collaborative Management of the Mexican Coast. Public participation and the oil industry in the Terminos Lagoon Protected Area. Master's Thesis. Simon Fraser University, Canada.

Day, Jr. J. et. al. 2003. Using ecotechnology to address water quality and wetland habitat loss problems in the Mississippi basin: a hierarchical approach. Biotechnology Advances 5291 (2003)

David, Laura T. 2000. Laguna de Términos, Campeche. LOICZ. Land Ocean Interface in the Coastal Zone. http://data.ecology.su.se/mnode/mexicanlagoons/terminos/terminosbud.htm

EPOMEX. 1992. Informe Anual, Julio 1991-Julio 1992. Proyectos de Investigacion. P. 33.

Estado de Tabasco. 2002. Plan Estatal de Desarrollo.

Estado de Tabasco. 2002 Programa Estatal de Desarrollo Social y Protección del Medio Ambiente

Frias, M. 2003. Proyecto Nacional Mexico Tercer Milenio. http://www.mexicotm.com/interior/p/p_boca_cerroenglish.html

Instituto Nacional de Pesca. 2000. Carta Nacional dePesca.

Labougle, Juan Manual. 2002. Atlas Territorial, Región de Términos. Espacios Naturales y Desarrollo Sustentable, A.C. Mexico City.

Leriche Guzman, Luis Fernando. 19951. Isla Del Carmen: La Historia Indecisa de un Puerto Exportatodor....El caso de la industria camaronera(1947-1982)

Niembro Rocas, A. no date. *Haematoxullum campechianum* . In: USDA Forestry Service. Tropical Tree Manual. Available Online: http://www.rngr.net/Reforestation/Publications/TTSM. See chapter 4.

Oczkowski, A. (2005). *Charaterizing seasonal water flows in the Términos Lagoon.* Narragansett, RI: Coastal Resources Center, University of Rhode Island.

Olsen, S., Padma, T. and Richter, B. 2006. A Guide to Managing Fresh Water Flows to Estuaries. Narragansett, RI: The Nature Conservancy and the Coastal Resources Center, University of Rhode Island.

Ortiz, N. 17 October 2003. Desmantelada flota pesquera. Tabasco Hoy.

The Nature Conservancy. 2003. Gulf of Mexico Watersheds. A Joint Proposal to USAID for New Site Assessments. June 16, 2003

Rivera, Iris. 12 Octubre 2003. Promueven pesca en zona restringida. Tabasco Hoy.

Rivera Arriaga, E. and G. Villalobos Z. 2001. Identificación de Problemas y Oportunidades para el Manejo de la zona costera de Campeche, Mexico. JAINA En Linea, Vol 12 no. 2

Rojas-Galaviz, J.L., A. Yáñez-Arancibia, J.W. Day, and F.R. Vera-Herrera. 1992. Estuarine Primary Producers: Laguna de Terminos---a Study Case. In, U. Seeliger, ed., Coastal Plant Communities of Latin America. San Diego: Academic Press.

Salazar, H., I. Castañeda Camey, L. Vidal. 2000. Women in Fisheries in Mexico. Women Crab Processors, Peninsula of Atasta, Municipality of Carmen, Campeche. In, Workshop on Gender and Coastal Fishing Communities in Latin America. International Collective in Support of Fish Workers.

Secretaria de Ecologia, Estado de Campeche. Online Map Server. http://www.ecologia.campeche.gob.mx/arcims/website/consulta-mapas.htm

SEDESOL, Estado de Campeche. Poblacion por Localidad 1995. Secretaria de Desarrollo Social, Direccion de Estadistica E Informacion. Drawn from INEGI, Censo 1995.

Toledo, Alejandro. 2003. Rios, Costas y Mares: Hacia un análisis integrado de las regiones hidrólogicas de Mexico. Instituto Nacional de Ecología, SEMARNAT, México, D.F.

Vargas Maldonado, Irma, A. Yáñez-Arancibia, 1987. Estructura de las Comunidades de Peces en Sistemas de Pastos Marinos (*Thalassia testudinum)* de la Laguna de Términos, Campeche México. Annals of the Instituto de Ciencias del Mar y Limnologia, Universidad Autónoma de México. 14 (2) : 181-196.

Yáñez-Arancibia, A, F. A. Linares, and J. Day. 1980. Fish community structure and function in Terminos Lagoon, a tropical estuary in the southern Gulf of Mexico. In: V. Kennedy (Ed.) Estuarine perspectives. The Fifth Biennal International Estuarine Research Federation Conference. Jekyll Island, Georgia. Oct. 7-12 1979. Academic Press Inc., New York 465-482.

Yáñez-Arancibia, A, A.L. Lara-Domíguez, A. Aguirre-Leon, S. Diaz-Ruiz, F. Amezcua Linareas, D. Flores Hernandez and P. Chavance. 1985.

Yáñez-Arancibia, A., A.L. Lara-Domíguez, P. Chavance, and D. F. Hernández. 1983. Environmental Behavior of Terminos Lagoon Ecological System, Campeche, Mexico. Annals of the Instituto de Ciencias del Mar y Limnologia, Universidad Autónoma de México. 10 (1): 137-176.

Yáñez-Arancibia, A., D. Zarate, J. Rojas-Galaviz and G. Villalobos. 1994. Estudio de declaratoria como area ecologica de proteccion de flora y fauna silvestre de la Laguna de Terminos, Campeche. In D. Suman, editor, El Ecosistema de Manglar en America Latina y La Cuenca del Caribe: Su Manejo y conservacion. Rosenstiel School of Marine and Atmospheric Science, University of Miami and the Tinker Foundation, New York.