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[1] In some instances, the sum total of emissions was adjusted based on the result of each of their individual components.

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4.0 DESCRIPTION OF THE PHYSICAL ENVIRONMENT

This chapter offers a detailed description of the current environmental conditions or the environmental baseline of the physical component in the Environmental Study Area of the Project. Wherever applicable and feasible, the pertinent description will be made, taking into account the General Study Area (GSA), Specific Study Area (SSA), and Area of Direct Impact (ADI) defined in the descriptive chapter of the Project. This Chapter includes the topics required for the physical component pursuant to Executive Decree No. 209; further, additional content was included for some specific topics that were deemed pertinent to better explain the existing status.

4.1 Geology

The description of the geological baseline presented herein includes information on the regional and local geological formation and the tectonic data of the area, among other information.

4.1.1 Methodology

The geological characterization was made primarily based on the information gathered from the studies provided by the Panama Canal Authority and the cartography related to this topic obtained from the Geological Map of the Panama Canal Zone (Stewart, R. H. *Et al.* 1980) provided by the ACP, as well as information obtained from onsite recognizance trips and with the aid of URS Holdings, Inc., Geographic Information System.

The purpose of this section is to identify and describe the most important geological events that have occurred in the area of study or nearby. Likewise, it is worthwhile to know the stratigraphic layout of the various formations that abound in the area and to describe the tectonic activity in the area. Lastly, it is also considered important to identify the geological material of the predominant formations in the areas that comprise the zones in which the Specific Study Area has been divided.

4.1.2 Regional Geological Formations

At the regional level, the geological studies of the central area of Panama, within which the Environmental Study Area is located, have revealed the presence of a well defined sedimentary basin. This basin extends from the Pacific to the Caribbean, across the Isthmus, forming an interconnected wall of thin and elongated basins.

The basin was developed where large faults disassociated the tectonic blocks of Choroteca and Chocó. The stratigraphic registers of this sector reflect the geological events that caused the separation of these large structural features.

Despite the number of detailed studies of this area, there is no agreement with regard to an adequate definition of certain formations, particularly within the Canal Watershed Area. The problem is due to the fact that certain types of locations have been covered by water, and others have been agglomerated into quarries.

The geological layering in the Environmental Study Area is dominated by sedimentary rocks (limestone, sandstone, clay) and volcanic (igneous, extrusive, basalt, limestone deposits), the large majority of which are from the Pacific sector. In Table 4-1, this geological layering is shown schematically for the Specific Study Area, according to the zones defined in this Environmental Impact Study.

Table 4-1
Geological Succession in the Specific Study Area

			Zones in the Specific Study Area*					
GEOCHRONOLOGY		STRATIGRAPHY	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
QUAT. (1.6 – actual)	PLEIST. (1.6 – 0.01)	Pacific and Atlantic Sludge (Mud)	Qa, Qr (1)	Non-differentiated Holocene Sediments– Qa			Disc.	Qa
PLIOCENE (5.3 – 1.6)	Upper	Discontinuity						
	Lower	Chagres Formation Tc	Tc	Absent	Tc	Absent		
MIOCENE (23 – 5.3)	Upper		Tc	Absent	Tc, Tb (2)	Tb, Td (3)	Tb	Tb, Td
		Gatun Formation Tg	Tg					
	Middle		Tg			Tb		
		Agglomerates Pedro Miguel – Tpa	Absent			Tpa		Absent
		Cucaracha Formation Tca	Tg	Absent	Tca			
	Lower	Culebra Formation – Tcb La Boca – Tl	Absent	Absent	Ta (4), Tba, (5) Tl, Tica (6), Tv (7)	Tcb, Tl, Tica, Tpa	Ta, Tca, Tl,	Tl
		Las Cascadas Agglomerates – Tlc	Absent	Absent	Tlc			Absent
OLIGOCENE (36.5 – 23)	Upper	Panama Formation - Tp Marine Facies – Tpm	Tct (8)	Absent	Tcm (9), Tcr (10), Tcv (11), Tp, Tpm	Tcm, Tct	Ta	
			Absent	Absent	Tbm (12)	Tba	Tp	
	Lower		Absent	Absent	Ta, Tbm, Tbo (13), Tp, Tpm	Absent	Tp	
EOCENE (57.8 – 36.5)	Upper	Gatuncillo Formation Tgo	Absent	Absent	Tgo, Tue (14)	Absent	Absent	Absent
	Middle		Absent	Absent	Tgo	Absent	Absent	Absent

Source: URS Holdings Inc. based on the 2005 Kirby study

Zone 1: The Atlantic Coast

Zone 2: Gatun Locks

Zone 3: Gatun Lake

Zone 4: Culebra Cut

Zone 5: Pacific Locks

Zone 6: The Pacific Coast

Notes

(1)	Qr	Holocene Coral Reefs
(2)	Tb	Basalt, Intrusive and extrusive, middle and upper Miocene
(3)	Td	Dacite, intrusive and porphyry dacite, Miocene
(4)	Ta	Andesite, intrusive and extrusive, lower Oligocene and Miocene
(5)	Tba	Bas Obispo Formation, Oligocene (¿) Agglomerate and hard tuff
(6)	Tica	Andesite, the same age as Las Cascadas Formation, lower Miocene
(7)	Tv	Non-differentiated volcanic rocks, lower Miocene or older
(8)	Tct	Limestone Bull Rock
(9)	Tcm	Caimito Formation, sandstone tuff, lutite tuff and limestone
(10)	Tcr	Caraba Formation, dacite and porphyry agglomerate
(11)	Tcv	Caimito Formation, volcanic facies
(12)	Tbm	Bohio Formation, marine facies
(13	Tbo	Bohio Formation, basaltic conglomerate
(14)	Tue	Marine rocks, sandstone and lutite, upper Eocene
(15)	Values (in parentheses) in first two columns, represent geological age according to: Zucol A. F. and M. Brea, 2000. Ages of the Earth. Center for Scientific Research CICYTTP- Diamante, Spain. *(Zucol A.F. y M. Brea, 2000. Edades de la Tierra. Centro de Investigaciones Científicas CICYTTP – Diamante, España.)*	

A generalized mixed section of stratigraphic units indicates that its thickness is of approximately 2,900 m of deposit. The representation in Table 4-1 has been prepared based on data contained in various publications that reflect an applied interpretation of this complex situation.

In this sense, the oldest stratigraphic unit within the Area of Ecological Study is the Gatuncillo Formation, which dates from the Middle Eocene and Upper Eocene. This formation consists of fine granular deposits interspersed with limestone. According to lithological and paleontological data submitted by Byy (1970; cited in The Louis Berger Group, 2004), the formation originated in an abyssal and bathyal environment.

After the Gatuncillo formation, following in stratigraphic sequence is the Panama formation, lower to upper Oligocene. Mainly andesite agglomerates in fine grain tuffs. It includes conglomerates deposited by currents. In the marine facies, this very formation is constituted by tuff sandstone, tuff lutite, algal and foraminifer limestone. There is Lutite sandstone in the basal part of the Quebrancha syncline. Next in sequence is Las Cascadas agglomerate, lower Miocene. Fine grain agglomerate and soft tuff. The features of this formation indicate their layering in shallow to moderately deep waters.

Immediately follows the Culebra formation, which is a marine sequence that contains carbonous schist, lignite, alluvium mudstone, and conglomerates. The formation that follows is called La Boca and dates back to the beginnings of the Miocene. Said formation stands out in a small area of the Panama Pacific Sector and has a lithological content quite similar to that of the Culebra formation. Following is the Cucaracha formation, which contains massive bentonitic clays, sandstones, conglomerates, and ash flows.

Following in the stratigraphic sequence is the Pedro Miguel formation, whose genesis was during the Upper Miocene. This formation interconnects with La Boca formation. It is of pyroclastic origin, with a thick texture that is generally hard to half-hard and dense. It is constituted of a single mass, moderately united, fine to coarse grains with small, angular fragments up to large masses of basalt in a sandy matrix of small, well-cemented conglomerates, with secondary calcite and some zeolite.

Finally, to complete the stratigraphic units in the Area of Ecological Study, there is the Gatun formation, originating in the Middle Miocene. This is the most significant stratigraphic unit at the regional level. It is composed of a medium to very fine grain calcareous or marlacious mass, with very little sandstones, but with conglomerates of small rocks, alluvia, and other minor conglomerates.

The Gatun formation in the Caribbean sector is covered and partially overlapped by the Chagres formation of the Miocene-Pliocene and consists of fine grain sandstone and alluvial fragments. The base of the Chagres formation is known as Bull Clay. The adjacent boundaries make contact with the oldest formations that consist of gray-bluish alluvium clay with sandy layers. The deposits occurred in areas of brackish water with an abundance of shells in an organic matrix of black alluvium. The portion of the formation deposited in swampland is composed principally of black, fine grain, organic, woody and other semi-decomposed vegetable matter mixed with alluvia, and light gray or yellowish gray soft and pliable plastic clay, over organic deposits. These phases are gradually intermixed laterally and the deposits are mainly horizontal.

The Holocene period is represented by mud on the Pacific side, gravel from the Chagres River in the central area and Atlantic mud in the Caribbean sector. The Pacific and Atlantic mud are similar in appearance as well as in their physical properties.

The Canal area features a diverse and complex lithological composition, which may be divided into five main types of materials.

- Sediments, clay, mud, and sand (fine grainy matter);
- Gravel and clay (coarse grainy matter);
- Soft rock with resistance lower than 15 Megapascals (Mpa);
- Half-hard rock with resistance between 15 and 50 Megapascals (Mpa);
- Hard rock with resistance above 50 Megapascals (Mpa).

The Atlantic area is composed of sediments, clay, mud, and sand. Most of the material in the Pacific area is considered hard rock, except the intermediate layer of earth, where most of the material is composed of soft materials from La Boca formation.

The geological map shows (Graph 4-1) that the dominant geologic formations in the Atlantic sector are:

- Non-differentiated sediments, mainly alluvium or fill (Qa) that practically covers the entire Limon Bay;
- The Gatun Formation (Tg), which consists of sandstone, lutite, tuff, and conglomerate that covers the Gatun area; and
- Bull Clay (Tct), which is the base material of the Chagres Sandstone formation. This covers a small area and is located close to the old French Canal.

Meanwhile, among those dominant in the Pacific Sector (Graph 4-2) are:

- La Boca formation (TI), which consists of clay schists, lutite, sandstone, tuff, and clay;
- The Chagres formation (Tb), composed of intrusive, extrusive, and volcanic rocks such as intrusive and extrusive basalt; and
- Cucaracha formation (Tca), bentonitic laminated clay, carboniferous laminated clay and, a thin layer of ignimbrite in the lower areas.

4.1.3 Local Geological Units

The local geology shown below has been identified for each of the six zones in of Specific Study Area and the Direct Impact Area. The tables shown in the following sections describe the geological materials that make up the different zones comprised in the Specific Study Area and which may eventually be exposed to the direct and indirect impacts arising as a consequence of the construction works in the Canal Widening Project.

4.1.3.1 Atlantic Coast

The Atlantic Coast (Zone 1) consists of five geological units or formations, of which those most represented in the Environmental Study Area, are the Qa (Differentiated Sediments) and the Qr (Coral Reefs), whereas the dominant formation for the Direct Impact Area is Qa (Graph 4-1). The Zone of the Atlantic Coast consists of the following geological materials:

Table 4-2

Geological Materials in Zone 1

Formation	Geological Unit	Period	Epoch	Strata Types
No Name	Qa	Quaternary	Holocene	Non-differentiated Sediments, mainly alluvium or fill
No Name	Qr	Quaternary	Holocene	Coralliferous Reefs
Chagres Sandstone	Tc	Tertiary	Upper Miocene or Lower Pliocene	Clumpy Sandstone, generally of a fine grain
Gatún Formation	Tg	Tertiary	Middle Miocene	Sandstone, Lutite, Tuff and Conglomerate
Bull Clay	Tct	Tertiary	Upper Oligocene	Coquina. Base matter of Chagres sandstone formation.

Source: URS Holdings Inc.

4.1.3.2 Gatun Locks

Zone 2, defined as Gatun Locks (Graph 4-1), has two geological formations, with the Gatun formation (Tg) the one of greater presence within the Area of Ecological Study, whereas the Qa (Differentiated Sediments) extends over the greatest area within the Area of Direct Impact, followed by the Gatun formation (Tg). Following are the geological materials that compose them:

Table 4-3

Geological Materials in Zone 2

Formation	Geological Unit	Period	Epoch	Strata Types
No Name	Qa	Quaternary	Holocene	Non-differentiated Sediments, mainly alluvium or fill
Gatun Formation	Tg	Tertiary	Middle Miocene	Sandstone, Lutite, Tuff, and Conglomerate

Fuente: URS Holdings Inc.

4.1.3.3 Gatun Lake

Zone 3, or Gatun Lake (Graph 4-1), is one of the most diverse from the geological point of view, inasmuch as it consists of 15 geological units or formations; within the Area of Environmental Study the Caimito formation (Tcm) is the one with greatest representation. Following are the Bohio (Tbo) and Gatun (Tg) formations. For the Area of Direct Impact the Bohio (Tbo) and Gatun (Tg) formations cover the largest area. This zone consists of the geological materials indicated in Table 4-4 below.

Table 4-4

Geological Materials in Zone 3

Formation	Geological Unit	Period	Epoch	Strata Types
No Name	Qa	Quaternary	Holocene	Sediments, non-differentiated, mainly alluvium or fill
No Name	Tb	Tertiary	Miocene middle and upper	Intrusive, extrusive and volcanic rocks, such as Intrusive and Extrusive Basalt
Bohío Formation, Marine Facies	Tbm	Tertiary	Oligocene lower to upper	Marine Facies, sandstone, calcareous and conglomerate with small pebbles
Bohío Formation	Tbo	Tertiary	Oligocene lower to upper	Conglomerate, mainly basaltic and sandstone (grauvaca)
Culebra Formation	Tba	Tertiary	Miocene lower	Calcareous sandstone and calcareous lutite
Caimito Formation	Tcm	Tertiary	Oligocene upper	Sandstone Tuff and Lutite Tuff, and limestone and tuff foraminifers
Caraba Formation	Tcr	Tertiary	Oligocene upper	Mainly agglomerate of porphyry dacite. In conglomerate, calcareous and limestone type area, both fossil
Caimito Formation	Tcv	Tertiary	Oligocene upper	Volcanic Facies, agglomerates and tuff grauvaca

Formation	Geological Unit	Period	Epoch	Strata Types
Gatun Formation	Tg	Tertiary	Miocene middle	Sandstone, Lutite, Tuff, and Conglomerate
Gatuncillo Formation	Tgo	Tertiary	Eocene middle to upper	Clay schists, Lutite, Quartz sandstone, algal limestone and foraminifer
Las Cascadas Formation	Tlc	Tertiary	Miocene lower	Agglomerate and soft, fine grain tuff
No Name	Tica	Tertiary	Miocene lower	Intrusive, extrusive and volcanic andesite rocks, the same age as Las Cascadas Formation, lower Miocene
No Name	Pt	Tertiary	Cretaceous	Anti-Tertiary. Basaltic and altered andesitic lavas and tuffs. Include diorite and dacite rocks
No Name	Tue	Tertiary	Eocene upper	Marine Rocks, Upper Eocene. Sandstone and lutite
No Name	Tv	Tertiary	Miocene lower	Non-differentiated volcanic rock. Generally lower Miocene or older.

Source: URS Holdings Inc.

4.1.3.4 Culebra Cut

Zone 4, also known as Culebra Cut (Graph 4-2), is made up of 10 geological units, among which La Boca formation (TI) and Tb (Intrusive and Extrusive Basalt) occupies the largest area within the Area of Ecological Study. In the Area of Direct Impact, the formations with the largest representation are La Boca (TI), Cucaracha (ca) and Tb (Intrusive and Extrusive Basalt). Table 4-5 shows the predominant geological materials in this zone.

Table 4-5

Geological Materials in Zone 4

Formation	Geological Unit	Period	Epoch	Strata types
No Name	Qa	Quaternary	Holocene	Non-differentiated sediments, mainly alluvium or fill;
No Name	Tb	Tertiary	Miocene middle and upper	Intrusive, Extrusive, and Volcanic Rocks such as Intrusive and Extrusive Basalt.
Bas Obispo Formation	Tba	Tertiary	Oligocene	Agglomerate and hard tuff
Cucaracha Formation	Tca	Tertiary	Miocene lower	Laminated bentonitic clay, carboniferous laminated clay and a thin layer of ignimbrite on the underside
Culebra Formation	Tcb	Tertiary	Miocene lower	Calcareous Sandstone and calcareous lutite
No Name	Td	Tertiary	Miocene	Intrusive dacite and porphyry dacite
La Boca Formation	TI	Tertiary	Miocene lower	Clay schists, lutite, sandstone, tuff, and limestone
Las Cascadas Formation	Tic	Tertiary	Miocene lower	Agglomerate and fine grain soft tuff;
No Name	Tica	Tertiary	Miocene lower	Intrusive, extrusive, and volcanic andesite, the same age as Las Cascadas Formation
Pedro Miguel Formation	Tpa	Tertiary	Miocene lower	Agglomerate, fine to coarse grain.

Source: URS Holdings Inc.

4.1.3.5 Pacific Locks

Zone 5 or Pacific Locks (Graph 4-2), has seven Geological formations, of which formation Tb (Intrusive and Extrusive Basalt) dominate the Area of Ecological Study, whereas Tb (Intrusive and Extrusive Basalt) and Pedro Miguel (Tpa) formations are the most representative for the Area of Direct Impact. The following materials are found therein:

Table 4-6

Geological Materials in Zone 5

Formation	Geologic Unit	Period	Epoch	Strata types
Basalt	Ta	Tertiary	Lower Oligocene and Miocene	Intrusive, extrusive, and volcanic rocks. Intrusive and extrusive Andesite.
Sin Nombre	Tb	Tertiary	Middle and Upper Miocene	Intrusive, extrusive, and volcanic rocks, such as intrusive and extrusive Basalt.
Cucaracha Formation	Tca	Tertiary	Lower Miocene	Laminated bentonitic clay, carboniferous laminated clay and a thin layer of ignimbrite on the underside;
La Boca Formation	TI	Tertiary	Lower Miocene	Clay schist, Lutite, sandstone, tuff, and limestone;
Las Cascadas Formation	Tic	Tertiary	Lower Miocene	Agglomerate and fine grain soft tuff
Panamá Formation	Tp	Tertiary	Lower to Upper Oligocene	Mainly agglomerate, generally andesite of fine grain. Includes conglomerates deposited by currents.
Pedro Miguel Formation	Tpa	Tertiary	Lower Miocene	Agglomerate, fine to coarse grain.

Source: URS Holdings Inc.

4.1.3.6 Pacific Coast

Zone 6, called the Pacific Coast, is made up of six geological formations, of which the La Boca (TI) is the dominant for the Area of Ecological Study as well as for the Area of Direct Impact (Graph 4-2). The following formations may be found in this zone:

Table 4-7

Geological Materials in Zone 6

Formation	Geological Unit	Period	Epoch	Strata Types
No Name	Qa	Quaternary	Holocene	Non-differentiated sediments, mainly alluvium or fill.
No Name	Ta	Tertiary	Lower Oligocene and Miocene	Intrusive, extrusive, and volcanic rocks. Intrusive and extrusive Andesite.
No Name	Tb	Tertiary	Middle and Upper Miocene	Intrusive, extrusive, and volcanic rocks, such as intrusive and extrusive Basalt.
No name	Td	Tertiary	Miocene	Dacite, intrusive and dacite porphyry.
La Boca Formation	TI	Tertiary	Lower Miocene	Clay schist, Lutite, sandstone, tuff, and limestone.
Panamá Formation	Tp	Tertiary	Lower to Upper Oligocene	Mainly agglomerate, generally fine grain andesite. Includes conglomerates deposited by currents.

Source: URS Holdings Inc.

4.1.4 Paleontological Resources

The rocky formations exposed along the Panama Canal contain a rich and diverse fossil register, which includes land organisms, among which are mammals, reptiles, and plants. There are fossil deposits of marine organisms, which consist of foraminifers, coralline algae, corals, crustaceans, mollusks, and echinoderms. Said fauna and the rocks they inhabit were initially exposed during the Panama Canal construction from 1904 to 1914 (Vaughan, 1919[a]). The subsequent widening of the Panama Canal in the last one hundred years has continued to expose patches of diverse flora and fauna (Woodring, 1957-1982; Whitmore and Stewart, 1965; Blacut and Kleinpell, 1969; Johnson and Kirby, 2006).

With the purpose of determining the paleontological potential in the Panama Canal Watershed, Kirby (2005) made an assessment of said resource in two areas along the Canal; in the southern area which comprise the La Boca, Culebra, Cucaracha, Pedro Miguel formations and the non-consolidated sediments of the Pacific silt, including the following zones within the Specific Study Area: Culebra Cut, Pacific Locks, and the Pacific Coast of the Specific Study Area; and in the northern area, which comprises the Gatun formation and the non-consolidated sediments of the Atlantic silt and includes the Atlantic Coast and Gatun Locks zones within the Specific Study Area. Following are the results obtained by Kirby (2005) in each of the formations and it also indicates their fossil-containing potential.

- **La Boca Formation**

La Boca formation is very fossiliferous; in it are abundant fossils of bivalves, gastropods, decapods, and plants. Sixteen fossil sites were identified in the southern area; five of these sites are above ground and 11 are below ground. Also reported was the existence of marine fossils, including the tooth of a shark.

Taking as references, a review of the literature, interviews and onsite assessments, La Boca formation is rich in fossils with the presence of vertebrate, invertebrate, and plant fossils. Thus it may be determined that said formation has a high paleontological potential; that is, high probabilities of containing fossils. The increment of sampling at sites within La Boca formation, on the surface as well as below surface, will have a high probability of containing fossils.

- **Culebra Formation**

In the Culebra formation, there is the presence of abundant bivalve, gastropod, decapods, and plant fossils, in addition to fossils of land mammals, specifically cf. *Merycochoerus matthewi* (ancient artiodactyl of the extinct family of the oreodont). Likewise, marine fossils have also been reported in the Culebra formation, and the jaw of a crocodile was found. It is worth nothing that two fossil sites have been identified in this formation.

Taking as references, a review of the literature, interviews and onsite assessments, Culebra formation is rich in fossils with the presence of invertebrates, plants, and vertebrates, including land mammals. Thus it may be determined that said formation has a high paleontological potential of containing more fossils in the area south of the widening area.

- **Cucaracha Formation**

Cucaracha formation is rich in fossils. In the Cucaracha formation has been found the fossils of land mammals among them a large molar of rhinoceros of the specie *Floridaceras whitei*. The presence of non-marine gastropods (*Hemisinus* aff. *H. Oeciscus*) has also been reported, as well as fossils of *Paratoceras wardi* (ancient artiodactyl belonging to the extinct family of the *Protoeratidae*); likewise, the remains of rhinoceros, horses, and other large mammals have been collected from the Cucaracha formation.

In conducting onsite recognizance, 10 fossil sites were found in the Cucaracha formation area. Seven of these sites are on the surface and the other three are below the surface. Inasmuch as the review of the literature as well as the interviews and onsite assessments show that the Cucaracha formation has land mammals, reptiles, invertebrates, and plants, it has been determined that this formation has a high paleontological potential of having additional fossils in the area south of the widening.

- **Pedro Miguel Formation**

The Pedro Miguel formation is not fossiliferous. The presence of fossils in this formation has not been reported during the onsite assessments or from previous studies. Interviews also corroborate that there has not been any fossil discovery to date. Inasmuch as the review of the literature as well as interviews and onsite assessment show that Pedro Miguel formation is not fossiliferous, it has been determined that this formation has a low paleontological potential; that is, its probabilities of containing fossils are few.

- **Gatún Formation**

Gatun formation is very fossiliferous. Previous studies have found a variety of fossils, ranging from microscopic organisms (foraminifers) to large mollusks, which point to a rich history of fossil discovery in this formation that date back to the latter part of the 19th century (Conrad, 1855; Gabb, 1881; Brown and Pilsbry, 1911, 1913; Woodring, 1957-1982; Van den Bold, 1967; Graham, 1991[a], 1991b, 1991c; Collins and Coates, 1999). In the assessments conducted an abundance of bivalve and gastropod fossils were found in this formation. Likewise, in onsite studies conducted, 26 sites were found to have fossils, of which four were present on the surface and 22 on the sub-surface. Drillings made prior to this assessment report the existence of marine fossils and indicate, further, that nautiloids may be found in abundance in the Gatun formation.

Inasmuch as the review of the literature as well as the interviews and onsite assessments show that the Gatun formation is very fossiliferous as it concerns marine vertebrates and invertebrates, it has been determined that this formation has a high paleontological potential of containing fossils.

- **Pacific Silt and Atlantic Silt**

In the two areas of assessment (south and north), there are non-consolidated deposits of the Quaternary age. The Pacific Silt is located in the southern assessment area and the Atlantic Silt is located in the northern assessment area. The onsite assessments were unable to determine whether these units contain fossils, but the review of the literature determined that during the construction of the Panama Canal, clams, other mollusks and vegetation were found locally (Dall, 1912; Brown and Pilsbry, 1913). The exact age of these sediments is unknown, but it possible that they date back to the Pleistocene.

Inasmuch as the literature review suggests that there may be Quaternary fossils present in the Pacific Silt and the Atlantic Silt, it has been determined that these deposits have a high paleontological potential of containing fossils. Although land mammals have not been found in these deposits, similar deposits at other sites have produced land mammals of the Pleistocene (Gazin, 1957; Pearson, 2005).

To conclude, Kirby (2005) determined that the formations of La Boca, Culebra, Cucaracha, Gatun, and the Atlantic Silt and the Pacific Silt hold a high potential of containing paleontological resources. Further, this author managed to identify 52 fossil sites, of which 16 were surface and 36 were sub-surface. Finally, it is worth noting that 408 fossil specimens were found, including 178 vertebrates (land mammals and reptiles), 213 invertebrates (bivalve, gastropods, decapods, percebes, and foraminifers), and 17 specimens of vegetation (palm, petrified wood, mangroves, seeds, and roots).

4.1.5 Geotechnical Characterization

Geotechnics is a new branch of science in geology that studies the behavior of rocks and soils exposed to any civil works. Geotechnics will determine the stability, resistance, and viability of these materials in light of the construction of development works.

In this framework, this Environmental Impact Study for the Canal Widening Project presents the geotechnical characteristics of some geological formations present in the Specific Study Area. Said formations were selected for characterization because they are in sites of interest selected for the construction of civil works, and which include the construction of four new dams on the Pacific side, as well as the construction of the new Miraflores and Pedro Miguel locks. The stated geotechnical characterization is located within the Ecological Study Area in the zones of Culebra Cut (Zone 4) and the Pacific Locks (Zone 5). Geological and geotechnical explorations conducted in said area indicate that among the most plentiful materials found are strong basalt with variable fractures and weak sedimentary rocks in lesser amounts.

Following is a description of the Geotechnics characteristics of the geological formations explored and Table 4-8 shows the standards used in the description of the rocks. The location of these formations, with regard to the specific study areas were already presented in section 4.1.3.

- **Basalt**

Basalt is described as a rock of medium to very high hardness (RH-3 to RH-5). The texture of this rock is typically fine grain and of porphyritic texture (large crystals in a fine mass of earth). Basalt includes gabbro and diabase. Basalt is vesicular (there is the presence of gas in the formed cavities) with zeolite present as a fill along the veins. Basalt is described 1) compact rock; 2) rock joined in the shape of a column and 3) rock that is highly fractured.

In general, the quality of the basalt rock is good. The maximum resistance to compression (UCS) of this rock surpasses the approximate average of 55 Mpa, and it has a median specific gravity of approximately 2.73. It is improbable that basalt is affected by air, humitdiy, or other geochemical changes. Likewise, basalt may be fractured and fused at a variety of degrees;

therefore, it can be fragmented in a wide range of sizes. Further, it can also be crushed and used in the production of sandy and gravel materials. Basalt may be broken into angular shaped particles and still maintain its hardness; likewise, its abrasive resistance to sulfate and its alkaline reaction are to be considered in using this rock as aggregate material for concrete.

- **La Boca Formation**

This formation is constituted by a sedimentary array that has a wide range of rock varieties. The formation contains sandstone, limonite, agglomerates, and tuff. The hardness of the rock in this formation varies from very soft to moderately high (RH-1 to RH-3). La Boca is formed by well-flattened sedimentary layers. The bedrock formed by sandstone tends to be massive exposures in a shelf pattern. The most competent spacing in this formation hast a number of joined layers. For its part, the limonite layers are laminated and meteorized in small fragments, while the sandstone is broken in blocks with smooth corners and edges. Hydrothermal alterations have affected this formation, for which there is a high percentage of clay minerals in it, which are mostly montmorillonite, and ilmenite

The relatively soft rocks (sandstone, lutite, slate, and tuff) within La Boca are predominantly of a fine grain. The typical soils include sandy clay, swampy sand, silt, and clay. Limonite and sandstone tend to be affected by air and weather conditions, especially when the latter changes quickly from humid to dry. The formation may have a varying percentage of mix between strong and soft materials due to its flattened feature.

- **Pedro Miguel Formation**

Pedro Miguel formation has a superior unit of agglomerates and a lower stratum of limonite and sandstone. The agglomerate is covered by basalt. Contact between the agglomerate and the basalt that covers it appears as transitional, since part of the agglomerate may be found on top of the basalt. The agglomerate is mainly a unit of hard rock made up of basalt fragments and locally has material similar to a soil, in addition to clay filling the spaces between the basalt fragments. The erosion of the cores occurs typically on the basalt fragments, which are surrounded by highly irregular fractures.

The agglomerate consists of a layer of limonite and sandstone that includes several tens of meters of thickness. Limonite is a rock of low to moderate hardness (RH-1). Sandstone is also a rock of moderate hardness with local cementing. The fine grain layer of the Pedro Miguel formation is lateral transition to La Boca formation.

The agglomerate probably produces less consistent fragments than those originated from the Basalt formation previously mentioned. Likewise, the strength of the agglomerates is more variable, because of its variable erosion and alteration.

The pyroclastic materials of the agglomerates are generally solid and strong, but the agglomerates tend to break off in rounded fragments, similar to those generated by a high percentage of residual materials owing to penetrating erosion and alteration. The material could be broken to such a degree that it would affect its placement and compacting.

- **Cucaracha Formation**

Cucaracha formation is made up in large part of a weak claylike slate. The middle layer of the formation contains volcanic tuff, which changes to clay minerals. Clay minerals are benthonic as a result of the hydrothermal alteration of the volcanic ash. Laboratory granulometry studies indicate that these materials are mainly plastic slime and plastic sandy slime with high plasticity clay and swampy sand to a lesser degree. The clay content in clay slate and limonite is in a range higher than 50%. The liquid limit is of approximately 50 to 60%, and the plasticity limit is between 25 to 40%. Clay slates and limonite may break into predominantly fine grain materials, which could be hard to handle during the rainy season, because of the benthos content of Cucaracha formation.

- **Surface Unit**

A relative thick soil, has formed locally over basalt and the agglomerates. The basalt soil has a very plastic clay consistency and contains throughout eroded fragments of basalt. The erosion of the basalt fragments ranges from eroded layers to completely eroded fragments with some rocklike texture (saprolite). The range of consistency covers from soft to firm. The upper portion of La Boca formation is also eroded, and it consists of clay, sediments and fine grain sand. The consistency may be medium to high and of moderate plasticity. The eroded sedimentary material is described in the zone as residual and saprolitic; the material is within the erosion profile typically described as "overcharge".

The eroded rock and residual soil would be difficult to segregate during a classification. The residual soils developed from basalt and agglomerates are mainly of highly pliable clay. These materials may be hard to handle in the rainy season. Work on this material would require the removal of the basalt fragments contained in the clay to improve compaction and the quality of the same.

Table 4-8

Description Standards of Rocks Obtained from Borings in the Canal Area

Hardness	**Field Test**	**Resistance**	**UCS kg/cm^3**	**UCS[2] Lb/plg^2**	**UCS Mpa/PLT[3] Index (ls)**
Soft or Very Soft **RH-1**	Does not crumble in hand, but is chipped very easily with pick hammer	Very Weak to Weak	10-250	142-3,555	0.98-24.5 (ls<1) RO<1 R1-1-5 R2-5-25
Moderately Soft **RH-2**	Is chipped with slight hammer blows (pick), is easily cut with a knife	Weak to moderately strong	250-500	3,555-7,111	24.5-49 (ls=1-2) R3-25-50
Moderately Hard **RH-3**	Is chipped with moderate hammer blows, it is difficult to cut with a knife.	Moderately strong to strong	500-1,000	7,111-14,223	49-98 (ls=2-4) R4-50-100
Hard **RH-4**	Is not chipped with the hammer; breaks in fragments from moderate blows from the flat side of the hammer.	Strong to very strong	1,000-3,000	14,223-28,477	98-196 (ls=4-8) R5-100-250
Very Hard	Breaks into fragments from hard blows	Very strong	> 3,000	> 28,477	>196

2 UCS = Unconfined Compressive Strength.
3 PLT = Point Load Test .

RH-5	from the flat side of the hammer.				(ls>8) R6>250

Source: ACP standard of hardness and resistance used in the geological description compared to the resistance classification of the Canadian Foundation Engineering Manual, 1992 Adapted IPIG – 2004 for the Landslide Control Program.

4.1.6 Tectonics

In the Gulf of Panama there are nine (9) thrust faults toward the West that extend parallel to Las Perlas Archipelago with a NNW-SEE rift, which seem to be active because the marine floor curves toward the southeast of the archipelago (Cowan, 2001).

Based on geophysical data and topographic and fault parameters, some authors have proposed that there is a tectonic boundary line that cuts the Isthmus of Panama in half, and it runs along a NNO-SSE orientation and has been called the Canal Discontinuity or the Gatun Fracture Zone (Case 1974; Lowrie *et al*. 1982). It is believed that the trail of the deformity connected to this discontinuity continues into the sea at the Deformed Belt of Northern Panama *[Cinturón Deformado Panamá del Norte (Vitali et al. 1985)]*. Recent studies by Schweig et al. (1999) and Cowan (2001) have not found any indication, neither geological or geophysical, that said structure exists and they suggest that if it exists, it has to be over 3 - 5 millions years, inasmuch as sediments found of equal or lesser age than that has not shown any evidence of deformity.

Corrigan y Mann (1985, 1990), have suggested that the faults in this region are normal discontinuities, located at N 40º E y N 70º E; some of the faults, like the Río Gatun fault, show a course component. The Gatun fault is the most important of these faults. It is active but produces a very low level of micro seismicity. Geological and paleo-seismological studies conducted in the field (Schweig *et al.* 1999), suggest that this is a normal fault with a southerly course and that the biggest event occurring at this fault was an M6.8 with a repeat cycle of 10,000 to 20,000 years. With a seismic reflection, Pratt *et al* (1996, 1999), found a fault with an active course of a N-S direction with 5 kms. of the Gatun dam in the southern area of Limon Bay (Graph 4-1).

With regard to the faults present in the Project area, it is found that the General Study Area is crossed by four (4) main faults, which are the Rio Gatun, Caballo, Limon and the Azota fault, which are located toward the Eastern area of the General Study Area (Graph 4-1). Meanwhile, toward the Specific Study Area, in the Gatun Lake zone, there is a prolongation of the Azota fault and there are some small unnamed faults (Graph 4-1). Toward the areas of Culebra Cut and the Pacific Locks, included in the Specific Study Area, the faults of Rio Pedro Miguel and Miraflores have been identified, as well as a series of unnamed faults (Graph 4-2).

4.2 Geomorphology

The geomorphologic characterization of the Environmental Study Area (Canal watershed) was conducted primarily based on the information gathered from the studies carried out by ACP and the mappings related to the matter obtained from the Geomorphology Map in the National Atlas of the Republic of Panama (Tommy Guardia National Geographic Institute, 1988) and from the GIS data base provided by the ACP.

The region is characterized by numerous hills of a conic shape. The faults and folds play a secondary role in the configuration of the scenic features. There are well developed and sharply defined drainage patterns, even though its geological age is relatively recent.

In other words, at the place of the transition from the drainage between hard and soft formations, there is a notable widening of the valleys and a leveling of the profiles of rivers and brooks. After the close of the period of intense volcanic activity at the beginning of the Miocene, four continent-shaping movements took place and the resulting erosive and depositional intervals created the present land mass.

During the first movement, the central portion of the Isthmus was elevated above the coastal lines resulting in the bent plane in a very profoundly dissected area, mainly in the interior that skirts along the Pacific and Atlantic coasts. The present morphology of the area was developed principally during this period, as well as the large variety of observable landmasses in the Central and Pacific portions. A second movement elevated the terrain to more than 90 meters in the Atlantic area.

While these valleys were still relatively young with prominent slopes and drop-offs, the land surface entered a third movement, which was a slow settling. In some instances, the lower parts were overtaken by the sea, as is evidenced by the layers of marine deposits with strictly fluvial beds in the Atlantic mud, based on marine fossils. This submerged period may be assigned to the Pleistocene.

The fourth and last movement was the appearance of valleys filled with sediments and coastal lines; the mud deposits or organic deposits were brought to their present level of a few meters above tide, and the Pacific sector islands were taken to their present elevation.

4.2.1 Local Geomorphology

The Environmental Study Area consists of sedimentary and igneous rocks, the latter are distributed toward the central part and the sedimentary toward the Caribbean and Pacific ends of the Watershed. The predominant outline of this sector is that of low regions and coastal plains, hills, slopes, and the mountain region. The outline for the area of study is shown in Graph 4-3. Following is the description of the local geomorphology of each of the zones that make up the Specific Study Area.

4.2.2.1 Atlantic Coast

The Atlantic Coast or Zone 1 is characterized by the presence of formations from the recent and present Quaternary period and of the Tertiary period (Graph 4-4).

The greater part of Zone 1 consists of formations from the Tertiary period, these are sedimentary rocks, valleys and colluvial alluvium plains, that are mainly east of the navigational channel, while in the southeasterly direction are extrusive igneous rocks and residual relief of high plains.

From the recent Quaternary period, in the coastal zones are formations of sandy low coast and marine abraded surfaces. On both coastal ends, East and West, of the Atlantic navigational channel are littoral cordons and arrows.

The outline of the zone is typical of low-lying regions and littoral plains.

4.2.2.2 Gatun Locks

In the Gatun Locks Zone or Zone 2, there are mainly formations of the Tertiary period, made up of sedimentary rocks, valleys, and colluvial alluvium planes (Graph 4-4).

As in the preceding zone, the outline is typical of low-lying regions and littoral plains.

4.2.2.3 Gatun Lake

Zone 3, Gatun Lake, is the one that presents formations of greatest age, including some from the pre-Tertiary period (Graph 4-4). In this area there are formations of extrusive igneous rocks of the pre-Tertiary period; sedimentary rocks, alluvium – coluvial valleys and plains of the Tertiary period; extrusive igneous rocks and residual outlines also dating back to the Tertiary period; glacis or esplanades from the ancient and middle Quaternary; and in lesser proportion, toward the southeast of the zone, surfaces of erosion and sedimentary rocks of the Tertiary period.

The outline of the zone is typical of that of low-lying regions and littoral plains; however, some hills and slopes may be seen there, too.

4.2.2.4 Culebra Cut

In Zone 4, Culebra Cut, there are only formations from the Tertiary period; most notable are extrusive igneous rocks and residual outlines to the west of the navigational channel, and eroded surfaces and sedimentary rocks in direction east of the navigational channel. To a lesser degree there may be observed, on the boundary line of Zone 5, sedimentary rocks, and colluvial-alluvium valleys and plains (Graph 4-5).

The outline includes low-lying regions and littoral plains, as well as some hills and slopes.

4.2.2.5 Pacific Locks

In Zone 5, Pacific Locks, there are formations from the recent and present Quaternary, ancient and middle Quaternary, and from the Tertiary period. There is the presence of overflow alluvial plains, from the recent and present Quaternary; glacis or esplanades from the ancient and middle Quaternary; and intrusive igneous rocks, residual relief, sedimentary rocks, valleys, plains, coluvial alluvium plains, and eroded surfaces—all from the Tertiary period (Graph 4-5).

With respect to the relief, the same is conformed by low lying regions and littoral plains.

4.2.2.6 Pacific Coast

The land portion of Zone 6, or Pacific Coast, presents formations of overflow alluvial plains corresponding to the recent and present Quaternary period and glacis or esplanades of the ancient and middle Quaternary period (Graph 4-5).

The relief of the Zone is that of low-lying regions and littoral plains as well as some hills and slopes.

4.3 Soil Characterization

As a part of the soil characterization, this section will describe the types of soil present in the area of study, the use of soils, delimitation of property, as well its usage capacity and capability.

4.3.1 Objectives and Methodology

The purpose of this section is to present a description and characterization of the soils in the Specific Study Area and in the Area of Direct Impact of the Panama Canal Widening Project. Initially, a general identification and description is made of the soils in which their main constitutional characteristics and properties are highlighted. The land use for different sectors within the Specific Study Area and the Area of Direct Impact is also presented, as well as the relevant aspects with regard to the delimitation of the property. Finally, soil capacity and capability are described for each zone of interest.

For this analysis, existing information on the study of soils conducted for the definition of the Regional and General Plan for the Development of the Interoceanic Region of Panama, *(Plan Regional y General para el Desarrollo de la Región Interoceánica de Panamá)* approved by Law No. 21 of July 2, 1997 was used; also information from the Ministry of Housing Plan for Urban Development of the Metropolitan Areas of the Pacific and the Atlantic, (*Plan de Desarrollo Urbano de las Áreas Metropolitanas del Pacífico y del Atlántico del MIVI)* approved by Executive Decree No. 205 of December 28, 2000; and the National Authority for the Environment map land covering; and the ACP Board of Directors Agreement No. 102 of August 25, 2005, adopting a plan for the use of soils. Further, additional information from the followings studies was also used:

- Environmental Base Line for the Environmental Impact Study for the Widening of the Panama-Colon Freeway, Section 1 (URS Holdings, Inc., 2007).
- Environmental Evaluation of Options for the Construction of New Locks and Deepening of the Pacific and Atlantic Approaches to the Panama Canal (Louis Berger Group, 2004).

In analyzing the topography of the soils in the Area of Direct Impact, the topographic and cartographic data of the Panama Canal Authority were used. The basic information was analyzed and processed using the Geographic Information System (GIS) and ERDAS 8.5 y ARCGIS software. Coverage of ranges of slopes and current land use to evaluate the potential use of the soil according to its capacity for use in agro ecology and to make possible an estimate of the soil loss resulting from water erosion in the environmental impact evaluation phase.

The capacity and capability for use of soil was determined with the use of the method employed by the Tropical Agronomy Center for Research and Teaching (1985), using information of slopes, depth, erosion, flooding, drainage, and toxicity.

4.3.2 Identification and Description of Soils

From the studies of soil conducted in the General Study Area, which includes the Panama Canal Watershed, it may be established that the dominant soils in the region are acid soils,developed from the originating material of rocks and igneous conglomerates under intense processes of meteorization classified as Ultisol. These soils are acidic, infertile, and most of them have lost the top layer because of recurring eroding processes. Said soils are less erodible; that is, they are less susceptible to water erosion than other types of soils in the area. On the alluvial plains of the main rivers such as the Chagres, Gatun, and Gatuncillo, there are recent alluvial soils which are classified as Entisols. These soils are of a coarser texture, less clay-like than the Ultisol and more fertile. In areas of material originating from limestone, soils have developed with greater organic material and fertility that, nevertheless, are less resistant to the water erosion.

4.3.2.1 Ultisol Soils

In the greater portion of the area acid Ultisol soils are predominant, covering about 70% of the Direct Impact Area. These soils were formed originally from the generating material of rocks and igneous conglomerates. A typical profile of this type of soils present a surface horizon between ocrico and umbrico and the greater concentration of organic material is of variable thickness, between 8 and 20 centimeters of depth. It is common in the soils of the region for this horizontal surface has been already eroded, consequently it is not present and what is exposed on the surface is an argilic horizontal subsurface; that is, an accumulation of “Bt” clay. This argilic horizon is much more leached and acid than the ocrico surface and it typically maintains a reddish coloration because of the abundance of iron oxides (Photo Attachment 2–Soil - Photo 1).

As may be seen from the characterization of the profile of this type of soils (Table 4-9), it presents a horizontal clay surface with an accumulation of organic material resulting from the processes of decomposition and deposition of various organisms that live in or on the surface of the soil. The first sub-surface horizon shows an accumulation of clay, product of migration in time throughout the porous medium of the clay fraction. This condition defines a horizon known as argilic at 20 to 40 centimeters of depth at the sites where the same has not been removed or lost by water erosion.

In a typical soil profile, there follows two to three horizons that are also clay-like, where the organic material and nutrients begin to diminish as it deepens. In general, in the region of the Panama Canal Widening Project, those soils classified as Ultisol are moderately deep to deep, acidic, of low fertility, and a little more resistant to water erosion than alluvial soils.

Table 4-9

Characterization of the Typical Profile of an Ultisol Soil

Horizon	Depth (cms)	Sand (%)	Slime (%)	Clay (%)	M.O. (%)	pH	Ca (me/100g)	Mg (me/100g)	K (me/100g)	Na (me/100g)	Acidity (me/100g)	Cations Σ
A	0-20	30	30	40	3.02	5.3	1.81	2.09	1.32	0.16	1.4	8.4
Bt1	20-40	31	20	49	2.68	5.2	3.29	2.49	0.5	0.07	3.9	6.35
B2	40-75	24	22	54	0.87	5.5	1.54	1.1	0.2	0.09	4.8	2.53
B3	75-110	26	18	56	0.67	5.4	5.54	1.74	0.31	0.10	4.3	3.25
C	110-180	24	26	50	0.2	5.1	1.7	4.7	0.14	0.1	3.5	6.71

Source: Regional Plan for the Development of the Interoceanic Region of Panama *(Plan Regional para el Desarrollo de la Región Interoceánica de Panamá)*, 1996 Volume 2. Annex C

4.3.2.2 Alluvial Soils

Alluvial soils are found on the flood plains of the rivers Chagres, Gatun, Chilibre, Gatuncillo, and their tributaries. These soils are characteristically plain, with few stones, less clayey and more fertile, intrinsically, than the Ultisols. Alluvial soils are classified as Entisols because they are soils of the very recent alluvial plains and have no diagnostic horizons in the profile of the soil. Texture is more uniform and they encompass from the truly clayey to clayey (Photographic Annex 2 - - Soil - Photo 2).

Inasmuch as they are of recent deposition, from the pedological point of view, they do not present diagnostic horizons. Their main limitation is the potential for flooding because they are in areas under the impact annually of the rising levels of rivers or water reservoir dams. Table 4-10 shows the characterization of a typical profile an alluvial soil in the Gatun River.

Table 4-10

Characterization of the Typical Profile of an Alluvial Soil

Horizon	Depth (cms)	Sand (%)	Slime (%)	Clay (%)	M.O. (%)	pH	Ca (me/100g)	Mg (me/100g)	K (me/100g)	Na (me/100g)	Acidity (me/100g)	Cations Σ
A	0-17	46	24	30	5.24	6.3	4.77	5.57	1.32	0.10	0.1	10.72
B1	17-35	41	24	35	1.85	5.8	2.83	1.53	0.5	0.14	0.3	8.95
B2	35-65	34	28	38	1.51	5.8	2.25	2.1	0.2	0.14	0.5	9.43
B3	65-95	43	20	37	1.17	6.0	4.10	3.5	0.31	0.12	0.3	10.21
B4	95-140	56	16	28	0.85	5.7	2.92	2.6	0.14	0.1	0.4	8.75

Source: Regional Plan for the Development of the Interoceanic Region of Panama *(Plan Regional para el Desarrollo de la Región Interoceánica de Panamá)*, 1996 Volume 2. Annex C

4.3.2.3 Sedimentary Origin Soils

In the General Study Area there are meteorized soils generating from sedimentary material such as those from the Gatun, Gatuncillo, Caraba, and Bohio formations, among others. Because of the originating material, they are less acidic, having a pH in a range of 5.9 to 7.2 and levels of organic matters, phosphorous, calcium, and magnesium of the most fertile in the entire Area of Direct Impact. (Table 4-11). Typically they present a mellite or umber surface horizon of variable depth. Its capacity for erosion is greater than the Ultisols because of their low aluminum content.

Table 4-11

Characterization of the Typical Profile of a Soil of Sedimentary Origin

Horizon	Depth (cms)	Sand (%)	Slime (%)	Clay (%)	M.O. (%)	pH	Ca (me/100g)	Mg (me/100g)	K (me/100g)	Na (me/100g)	Acidity (me/100g)	Cations Σ
A	0-18	34	18	48	5.7	7.1	4.88	4.67	0.64	0.18	0.3	12.17
B1	18-38	30	12	58	3.2	7.0	5.82	4.18	0.24	0.14	0.2	12.95
B2	38-60	26	14	60	1.74	6.9	6.92	4.97	0.17	0.10	0.1	12.19
C	60-75	12	24	64	0.87	7.2	7.24	4.36	0.10	0.09	0.1	12.35

Source: Regional Plan for the Development of the Interoceanic Region of Panama *(Plan Regional para el Desarrollo de la Región Interoceánica de Panamá)*, 1996 Volume 2. Annex C

4.3.2.4 Anthropic Soils

In the Area of Direct Impact are soils of various types that receive recurring deposits of sediments and materials removed from the operation sites of the Panama Canal Authority. In the case of the dredging of Gatun Lake, the sediments contain a greater concentration of slime, which is to be expected from lake sediments. Alteration from anthropical actions makes it difficult to characterize the same because of the variability of extracted materials, which are then deposited on the surface of the sites, making these originating materials for the formation of soils, which is interrupted by the addition of new materials.

From the point of view of the edaphology, these soils are classified as Entisols because they are of very recent formation and do not show any diagnostic horizon. The designation of Entresols that is normally destined to soils that have received contribution of nutrients or irrigation waters from man, in this case is framed in the strong impact that man has had in the process of conformation of these soils. Table 4-12 shows the characterization of a soil in the Sherman area in which the cited anthropic alterations are visible. In the case of the Sherman site, the main difference with the remainder of the soils of the area is evidenced in the slime contend that averages 38.5% when in the rest of the watershed the average is 20.52%. This value corresponds to an accumulation of more than 80% above the average.

Table 4-12

Characterization of an Anthropical Soil in the Sherman Region

Horizon	Depth (cms)	Sand (%)	Slime (%)	Clay (%)	M.O. (%)	pH	Ca (me/100	Mg (me/100	K (me/100	P (ppm)	Acidity (me/100g)	Cations Σ
A	0-25	29.0	39.0	32.0	5.2	6.0	6.4	3.4	77.0	0.01	0.1	10.9
B	25-55	30.0	38.0	32.0	1.9	6.0	6.1	2.2	120.0	0.01	0.2	9.3

Source: Regional Plan for the Development of the Interoceanic Region of Panama *(Plan Regional para el Desarrollo de la Región Interoceánica de Panamá)*, 1996 Volume 2. Annex C

Certain sites in the Area of Direct Impact where there are entresol soils are sites that have been used historically as Canal operations areas; therefore, their state of disturbance is very well documented prior to the implementation of the Panama Canal Widening Project (Photographic Annex 2 -– Soil - Photos 3 y 4).

4.3.3 Description of Soil Usage

Concerning the use of soil, it is important to note that the majority of the sites of direct impact of the Project correspond to areas that legally are of exclusive use to the Panama Canal Authority, and in the majority of them the activities being carried out are those related to the operation of the Canal. With regard to the use of soil in the Specific Study Area defined in this current Project, following is a summary of the main uses of each of these, while Graphs 4-6 and 4-7 show said use in a schematic form.

4.3.3.1 Atlantic Coast

In this Zone, which occupies a total of some 35.709 hectares, more than 60% corresponds to water areas for public use as well as for Canal operations. Within these water areas are the deposit site for the Western Breakwater, as well as the current Approach Channel of the Pacific entrance. Concerning the area occupied by the Area of Direct Impact within this zone, the water areas occupy 56.4% of the same.

Second in importance with regard to the soil uses of the area are the protected wildlife areas, which occupy 11.2% of the surface; within this classification are the protected areas of Galeta Island, San Lorenzo, and the recreational area of Gatun Lake. Within the Area of Direct Impact, however, this type of use is not being undertaken.

While 7.7% of the territory is for forestry/agro-forestry usage, almost 5% is used for industrial/office and about 3.7% (a little more or a little less in certain cases) are used as urban green areas, land area for Canal operations and an area of mixed-urban center usage.

Concerning the Area of Direct Impact, the main use, after water areas for Canal operations, is the land area of Canal operations, which comprises 36.5% of the Area of Direct Impact of the Atlantic Coast.

Table 4-13 shows the distribution of soil usage for the entire area, the Specific Study Area and the Area of Direct Impact.

Table 4-13
Soil Uses in Zone 1

Soil Usage	Total Hectares *	%	SSA (ha*)	%	ADI (ha*)	%
Water	15545	43.5	15534	44.2	11	1.9
Canal Operating Area-water	6988	19.6	6674	19.0	314	54.5
Urban Green Area	1361	3.7	1361	3.9	0	0.0
Impact Area and Hazardous Material	308	0.9	308	0.9	0	0.0
Canal Operating Area-land	1270	3.6	1060	3.0	210	36.5
Protected Wildlife Area	3984	11.2	3984	11.4	0	0.0
Industrial and Office Employment	1753	4.9	1738	4.9	15	2.6
Forestry / Agro forestry	2749	7.7	2749	7.8	0	0.0
Mixed Urban Center	1195	3.3	1169	3.3	26	4.5
Mixed Neighborhood Center	2	0.0	2	0.0	0	0.0
High Density-Residential	341	1.0	341	1.0	0	0.0
Low Density-Residential	192	0.5	192	0.5	0	0.0
Medium Density-Residential	21	0.1	21	0.1	0	0.0
Total	**35709**		**35133**		**576**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.

4.3.3.2 Gatun Locks

The area of Gatun Locks, or Zone 2, extends over a surface of approximately 902 hectares, dominated mainly by canal operating areas in about 80%. The land areas of canal operations occupy 66.9% of the zone, while water areas of the canal operations represent 14.1% of the same. In the case of the Area of Direct Impact, these zones occupy 94% of the same.

The third level of importance for said zone within the Area of Direct Impact is the soil use as Industrial-Office, which represents 9.1% of the surface of said area. Other uses present within the Area of Direct Impact of the zone include the urban green area, which accounts of 4.5% usage; forestry/agro forestry, accounting for 3.2%; and the low-density residential use, accounting for 2.0%.

Table 4-14 shows the different soil uses by type of area for this zone.

Table 4-14

Soil Uses in Zone 2

Soil Usage	Total Hectares *	%	SSA (ha*)	%	ADI (ha*)	%
Water	0	0.0	0	0.0	0	0.0
Canal Operating Area-water	127	14.1	4	1.3	123	20.9
Urban Green Area	41	4.5	39	12.6	2	0.3
Canal Operating Area-land	604	66.9	172	55.0	432	73.2
Employment-Industrial and Office	82	9.1	49	15.7	33	5.6
Forestry / Agro forestry	29	3.2	29	9.4	0	0.0
Total	**902**		**312**		**590**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.

4.3.3.3 Gatun Lake

Zone 3, known in the present study as Gatun Lake, includes approximately 58,228 hectares, of which 65.2% consist of water areas of Canal operations. This type of usage represents 99.7% of the Area of Direct Impact.

Another important use in the Gatun Lake Zone is that of the Protected Wildlife Area, which encompasses 15.4% of the Zone, and refers to Barro Colorado Island and a portion of the Soberania National Park. This type of usage represents only 0.1% of the Area of Direct Impact.

The following major soil uses in Zone 3 are as follows: 10.4% of land areas for canal operations, 5.5% for forestry/agro forestry; and 2.3% for impact and hazardous material.

Table 4-15 shows the various soil usages for the Gatun Lake Zone, or Zone 3.

Table 4-15

Soil Uses in Zone 3

Soil Usage	Total Hectares *	%	SSA (ha*)	%	ADI (ha*)	%
Water	90	0.2	90	0.2	0	0.0
Canal Operating Area-water	37954	65.2	34043	62.7	3911	99.7
Urban Green Area	139	0.2	139	0.3	0	0.0
Impact Area and Hazardous Material	1326	2.3	1326	2.5	0	0.0
Canal Operating Area-land	6041	10.4	6032	11.1	9	0.2
Protected Wildlife Area	8948	15.4	8945	16.5	3	0.1
Non-developed-undeclared Areas-land	14	0.0	14	0.0	0	0.0
Employment-Industrial and office	148	0.3	148	0.3	0	0.0
Forestry / Agro forestry	3228	5.5	3228	5.9	0	0.0
Thicket and Stubble	92	0.2	92	0.2	0	0.0
Mixed Urban Center	66	0.1	66	0.1	0	0.0
Mixed Neighborhood Center	14	0.0	14	0.0	0	0.0
Thatch	0	0.0	0	0.0	0	0.0
Grazing land	123	0.2	123	0.2	0	0.0
Fishery	26	0.0	26	0.0	0	0.0
Low Density Residential	9	0.0	9	0.0	0	0.0
Medium Density Residential	10	0.0	10	0.0	0	0.0
Total	**58228**		**54305**		**3923**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.

4.3.3.4 Culebra Cut

The Culebra Cut Area, or Zone 4, covers a surface of approximately 11,620 hectares, of which the greatest use of the zone corresponds to the category of protected wildlife area, accounting for 37.4%, represented mainly by the zone in which Soberania National Park is located. This type of usage is not present in the Area of Direct Impact.

Other relevant categories of soil usage in the area are the forestry/agro forestry and the use of land area for canal operations, which represents 31.3% and 21.0% of the territory, respectively.

This latter type of usage is of greatest importance for the Area of Direct Impact, representing 79.5% of the same.

Lastly, with a range varying from 3.6 to 2.1%, there categories of use such as impact area and hazardous materials, urban green area, and water area for canal operations.

Table 4-16 shows the various soil usage for this zone.

Table 4-16

Soil Uses in Zone 4

Soil Usage	Total Hectares *	%	SSA (ha*)	%	ADI (ha*)	%
Canal Operating Area-water	249	2.1	30	0.3	219	20.4
Urban Green Area	359	3.1	359	3.4	0	0.0
Impact Area and Hazardous Material	420	3.6	420	4.0	0	0.0
Canal Operating Area-land	2445	21.0	1591	15.1	854	79.5
Protected Wildlife Area	4343	37.4	4343	41.2	0	0.0
Employment-Industrial y office	60	0.5	60	0.6	0	0.0
Forestry /Agro forestry	3631	31.3	3630	34.3	1	0.1
Mixed Urban Center	93	0.8	93	0.9	0	0.0
Mixed Neighborhood Center	8	0.1	8	0.1	0	0.0
Medium Density Residential	12	0.1	12	0.1	0	0.0
Total	**11620**		**10546**		**1074**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.

4.3.3.5 Pacific Locks

In Zone 5, which covers some 8,136 hectares, the predominant soil usage is that of forestry/agro forestry, with a representation of 30.3% of the surface. Another important soil use is that of protected wildlife area, which represents 24.4% of the surface, and within which may be found the Camino de Cruces National Park and Metropolitan Natural Park.

Other relevant uses for the zone include land areas of canal operations, covering 14.9%; areas of impact and hazardous materials, covering 10.9%; low-density residential areas, covering 5.8%; and urban green areas, covering 5.3% of the territory.

For the Area of Direct Impact the main use is that of canal operating area-land, which takes up 65.3%, followed by the uses for canal operating area-water and the area of impact and hazardous material, each of these covering 14.9% of the Area of Direct Impact.

Table 4-17 shows the diverse soil uses for the Zone of the Pacific Locks

Table 4-17

Soil Uses in Zone 5

Soil Usage	Total Hectares *	%	SSA (ha*)	%	ADI (ha*)	%
Water	80	1.0	80	1.2	0	0.0
Canal Operating Area –land	281	3.5	81	1.2	200	14.9
Urban Green Area	430	5.3	429	6.3	1	0.1
Impact Area and Hazardous Material	884	10.9	685	10.1	199	14.9
Canal Operating Area-land	1216	14.9	342	5.0	874	65.3
Protected Wildlife Area	1987	24.4	1987	29.2	0	0.0
Employment-Industrial and office	27	0.3	27	0.4	0	0.0
Forestry / Agro forestry	2464	30.3	2427	35.7	37	2.8
Mixed Urban Center	133	1.6	133	2.0	0	0.0
Mixed Neighborhood Center	72	0.9	51	0.7	21	1.6
Thatch	18	0.2	18	0.3	0	0.0
Residential-low density	469	5.8	464	6.8	5	0.4
Residential-medium density	75	0.9	75	1.1	0	0.0
Total	**8136**		**6799**		**1337**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.

4.3.3.6 Pacific Coast

Zone 6, or the Pacific Coast comprises approximately 40,083 hectares, an their main use are for water areas, of which the water areas represent 56.7% and the water areas for canal operations cover 23.9% of the surface. In the Area of Direct Impact, the water areas of canal operations account for 86.6% of the same.

To a lesser degree, there is usage for industrial and office employment, covering 6.0%; usage for urban green area, covering 3.6%; and usage for mixed-urban center, covering 2.7%.

Table 4.18 shows the various soil usages for Zone 6.

Table 4-18

Soil Uses in Zone 6

Soil Usage	Total Hectares*	%	SSA (ha*)	%	ADI (ha*)	%
Water	22714	56.7	22577	63.6	137	3.0
Canal Operating Area-water	9569	23.9	5614	15.8	3955	86.6
Urban Green Area	1458	3.6	1407	4.0	51	1.1
Canal Operating Area-land	635	1.6	408	1.1	227	5.0
Protected Wildlife Area	746	1.9	746	2.2	0	0.0
Undeveloped-Undeclared Areas-land	3	0.0	3	0.0	0	0.0
Employment-Industrial and office	2424	6.0	2396	6.7	28	0.6
Forestry / Agro forestry	277	0.7	277	0.8	0	0.0
Mixed Urban Center	1091	2.7	984	2.8	107	2.4
Mixed Neighborhood Center	159	0.4	157	0.4	2	0.0
Residential-low density	711	1.8	653	1.8	58	1.3
Residential-medium density	296	0.7	296	0.8	0	0.0
Total	**40083**		**35518**		**4565**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.

4.3.4 Delimitation of Property

The Project will be carried mainly in areas that are patrimony of the ACP and in areas under its sole administrative jurisdiction, duly registered in the public registry. Therefore, the proposed Project will not require the acquisition of additional lands, except in certain concrete cases (E.g., Cocoli, Jose Dominador Bazan) in which lands and/or properties managed by other governmental agencies will be transferred.

According to the Panama Canal Authority Plan for Soil Usage (Agreement No. 102 of August 25, 2005, of the ACP Board of Directors) the Project is located within a zone of compatibility, patrimony of the ACP, in a Type I operating area, which corresponds to an area that is the property of ACP or the inalienable patrimony of the Nation, under the sole management of the ACP, which is critical for the operation and modernization of the Canal and for activities directly related to these functions. On the other hand, the Land Organization *(Ordenamiento Territorial)* established by Law 21, which takes into account the Regional Plan for the Development of the Interoceanic Region, the type of usage specified for the area where the Canal Widening Project will be developed included the areas reserved for Canal improvements, among other things, and the construction of the Third Set of Locks (ACP 2006).

4.3.5 Usage and Capability

Following is an analysis of the capacity and capability for use of soil in the area of study, based on agro ecological criteria.

4.3.5.1 Classification of Soils

The predominant use of the soil in the Area of Direct Impact of the Panama Canal Widening Project is reserved for the operation of the Panama Canal. In construction areas of the new locks, at both ends, Pacific and Atlantic, the use of the lands is related to the Plan of Soil Use of the ACP and to the Regional Plan for the Development of the Interoceanic Region.

Considering the soils as the basic environmental element for the development and sustenance of land ecosystems, the concept of maximum use capacity or soil capability is utilized. The capacity of soil usage, that is, the potential that a homogeneous unit of soil has to be utilized in a sustained manner without affecting its productive capacity, has been defined in term of the characteristics that determine its capability for Anthropic activities. The capacity of usage indicate the greatest use, capability or intense with which a determined unit of soil may be utilized. It is important to establish the capacity of use of the soil to be able to define necessary measures of mitigation and remedy for the Environmental Management Plan to be effective. According to CATIE (1985) the capacity for use of soils is determined by using the following agroecological parameters:

- Sloping
- Erosion
- Effective Depth
- Texture

- Stone Content
- Fertility
- Salinity / Toxicity
- Drainage
- Flooding
- Life Zone
- Dry Period
- Wind

In 1996, within the analysis of current and potential usage of the resources for the development of the Interoceanic Region of Panama, was defined the capacity for maximum usage of the soils by making use of edaphological information of existing soil studies.

According to the capacity of usage, soils may be used in activities of the type to which they belong or to activities of lesser intensity of usage that will guarantee it sustainability. The best soils are those of Class I, which because of their qualities do not have restrictions imposed on their use. To the extent that the classification number increases, the uses become more restrictive, arriving at Class VIII soils, which, because of their many limitations, should not be utilized for any activity except that of protection.

In general, the study areas of the principal limitations are slopes, fertility, and drainage. Soils having a higher usage capacity in the region are the alluvial (Classes III and IV), plains, and soils of limestone origins. Alluvials are relatively flat, of medium to good depth, while those of calcareous origins are more fertile but less deep and more susceptible to water erosion.

The general characteristics of the various categories for use of soils described in the Regional Plan of 1997 are presented below.

Class I Soils

These soils are arable soils, practically without usage restrictions.

Class II Soils

These soils are arable, with certain limitations in the selection of plants and they require moderate conservation.

Class III Soils

These are the best soils that have been found in the study area of the Panama Canal Widening Project. These soils have up to 5% sloping, of moderate depth, of medium to low fertility and low risk of flooding. They are found in areas of fluvial deposits of the hydrographic network. Their maximum usage suitability is for semi-permanent and permanent crops.

Class IV Soils

These the relatively flat soils with sloping of up to 9%; they are of moderate depth, medium to low fertility and moderate risk of flooding. They are found in areas of fluvial deposits of the hydrographic network and in calcareous soils. Their maximum usage suitability is for semi-perennial and perennial crops.

Class V Soils

Class V are those that are more suitable mainly for livestock use and perennial crops. Class V soils have sloping of up to 25% with some or several of the following limitations: shallow soils, very stony soils, moderate erosion problems, or severe risk of flooding. Their maximum suitability is for grazing and perennial crops and are also suitable for systems of management of sustainable agriculture. In forested areas, natural forest management is allowed.

Class VI Soils

Soils classified as Class VI are suitable for forestry production such as sustainable management systems, including agro forestry with fruit trees and coffee. Class VI soils have up to a 35% of sloping and some of the following limitations: very stony soils, severe erosion problems or moderate wind intensity.

Class VII Soils

Class VII soils have severe limitations, for which reason forestry management is only allowed in wooded areas, as long as the preservation of the forest is guaranteed. If the present soil usage is not for woods, the Forestry Restoration by Natural Regeneration *(Restauración Forestal por Regeneración Natural)* must be undertaken. Class VII soils have slopes of up to 60% and depths greater than 30 centimeters.

Class VIII Soils

Soils identified as Class VIII are stringently restricted areas for the preservation of the flora and fauna and the protection of areas with an over abundance of aquifers. These are soils with sloping greater than 75% and less than 30 centimeters of effective depth; included in this category are soils with very severe erosion problems. Also included in this category are soils within protected areas. In general, they are in the steepest and hardest-to-reach areas.

The description of the categories of sloping and agro ecological capacity of the soils is given below, with emphasis on the predominant characteristics of the soils in the area of study. The Soil Usage Map (Graphs 4-6 and 4-7) shows its distribution. The first inference that may be drawn is that in the area of study there are no Class I soils, and Class II is limited to about 5 hectares in Zone 1. Following is a description of the sloping and capacity categories for the soil usage within the Specific Study Area and the Area of Direct Impact of the different zones.

4.3.5.2 Atlantic Coast

As seen in Table 4-19, the soils in the Specific Study Area of the Atlantic Coast are mainly within the range of sloping of 25 to 45%.

In the Atlantic Coast region within the Area of Direct Impact, there is a predominance of flat soils with slopes of less than 7%, which have been described in a general manner since 1929 by Bennet as soils that are clayey, saturated swamps, mangroves, and dredge-filled southwest of the Gatun Locks.

Along the Atlantic Coast, at the estuaries of rivers and streams between Punta Toro and the estuary of the river Chagres are narrow strips of fine, loose sand. In the Specific Study Area, which includes Sherman and San Lorenzo are soils that have been developed from sedimentary materials such as sandstones and limolites and have sharper slopes than in the rest of the Atlantic Coast region.

In the Specific Study Area of the Expansion Program there are soils ranging from Class II to VIII. Table 4-20 shows that in the Area of Direct Impact the capacity of soil use is marginal, and the dominant classes are IV, V, VI, and VIII.

Table 4-19

Distribution of Slope Categories in the Atlantic Coast Zone

Ranges	SSA (ha*)	%	DIA (ha*)	%
0 - 7%	1928	14.9	198	78.8
7 - 15%	2371	18.3	10	4.0
15 - 25%	2438	18.9	9	3.8
25 - 45%	5342	41.3	27	10.7
45% and greater	847	6.6	7	2.7
Total	**12926**		**251**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.

Table 4-20

Distribution of Categories of Soil Use Capacity in the Atlantic Coast Zone

Usage Capacity	Total Area (ha*)	%	SSA (ha*)	%	DIA(ha*)	%
II	5	0.0	5	0.0	0	0.0
III	156	1.2	156	1.2	0	0.0
IV	4511	34.2	4479	34.6	32	12.7
V	1992	15.1	1842	14.3	150	59.7
VI	1997	15.2	1959	15.2	38	15.3
VII	2334	17.7	2334	18.1	0	0
VIII	2182	16.6	2151	16.6	31	12.3
Total	**13177**		**12926**		**251**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.. –Soils Studies of the Interoceanic Region of Panama.

4.3.5.3 Gatun Locks

In the Specific Study Area, the sloping categories are distributed among the different categories, and those slopes between 25% and 45% are dominant. In the Gatun Locks sector, it is common to find dredge fills made during the construction of Gatun locks in the period before 1914. Slopes in the Area of Direct Impact are relatively flat, less than 7% (Table 4-21).

The soil usage capacity is concentrated in Classes IV, V, VI, and VIII. Table 4-22 shows the surface and percentage corresponding to each category of soil usage of this sector.

Table 4-21

Distribution of Slope Categories in the Gatun Locks Zone

Ranges	SSA (ha*)	%	DIA (ha*)	%
0 - 7%	96	31.2	231	49.5
7 - 15%	47	15.3	74	15.8
15 - 25%	47	15.2	58	12.5
25 - 45%	110	35.8	44	9.5
45% and greater	8	2.5	60	12.8
Total	**308**		**467**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.

Table 4-22

Distribution of Categories of Soil Use Capacity in the Gatun Locks Zone

Usage Capacity	Total Area (ha*)	%	SSA (ha*)	%	ADI (ha*)	%
IV	401	51.8	156	50.7	245	52.5
V	235	30.3	106	34.4	129	27.7
VI	31	4.0	13	4.3	18	3.8
VIII	108	13.9	33	10.6	75	16.1
Total	**775**		**308**		**467**	

Source: URS Holdings, Inc. .. –Soils Studies of the Interoceanic Region of Panama.

4.3.5.4 Gatun Lake

The Gatun Lake Zone includes all the shores of Gatun Lake in addition to the insular soils, including the islands of Barro Colorado, Juan Gallegos, Tigre, Las Brujas, Zorra, Advent, Guacha, Guarapo, Gorgona, and Santa Cruz.

In Specific Study Area, which includes the insular areas of Gatun Lake, the predominant slopes are between 25% and 45%, mainly on the larger islands such as Barro Colorado and Juan Gallegos.

As seen in Table 4-23, the sloping of soils in the area around Gatun Lake, which define the Area of Direct Impact, is quite flat, as is to be expected in areas of riparian zones. More than 50% of slopes may be categorized as flat, between 0 and 7%.

Table 4-22 shows the categories of soil use in the Specific Study Area and the Area of Direct Impact of the Expansion Program for the Gatun Lake Zone. Class VI and VII soils represent more than 74% of the Specific Study Area, whereby its use is restricted to the majority of anthropic activities. Class IV soils predominate in the Area of Direct Impact.

Table 4-23

Distribution of Slope Categories in the Gatun Lake Zone

Ranges	SSA (ha*)	%	DIA (ha*)	%
0 - 7%	252	1.3	7	56.3
7 - 15%	1998	9.9	0	0.2
15 - 25%	3596	17.8	1	10.2
25 - 45%	10769	53.4	1	9.2
45% and greater	3555	17.6	3	24.0
Total	**20170**		**12**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.

Table 4-24

Distribution of Categories of Soil Use Capacity in the Gatun Lake Zone

Usage Capacity	Total Area (ha*)	%	SSA (ha*)	%	DIA(ha*)	%
III	4	0.0	4	0.0	0	0.0
IV	4579	22.7	4573	22.7	6	51.0
V	350	1.7	350	1.7	0	0.0
VI	6762	33.5	6760	33.5	2	13.0
VII	8196	40.6	8193	40.6	3	29.9
VIII	291	1.4	290	1.4	1	6.1
Total	**20182**		**20170**		**12**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.. –Soils Studies of the Interoceanic Region of Panama.

4.3.5.5 Culebra Cut

In the sector designated as Culebra Cut, red and acid Ultisoles soils predominate with the highest slopes in the entire area of study. In this zone, are the most prominent hills, such as Nitro, Contractor's, Empire, Hodges, Goyo, Paraiso, Oro, Marieta and Zion, among others.

Table 4-25 shows the categories of slopes in the Specific Study Area and the Area of Direct Impact for the Culebra Cut Zone. The Area of Direct Impact includes the following hills: Nitro, Oro, Paraiso, and Goyo, and the plains between the hills of Cocoli and Luisa. In the Specific Study Area there is a predominance of slopes between 25 and 45%; while in the Area of Direct Impact the slopes that predominate are those between the range of 0-7% and 24% - 45%.

As shown in Table 4-26, more than 87% of soils fall into the categories of usage VI, VII, and VIII, therefore its potential use is quite restricted for activities that are not those of Panama Canal operations. In the Specific Study Area, the dominant soils are those of category of use VI, while in the Area of Direct Impact, category VIII soils are predominant.

Table 4-25

Distribution of Slope Categories in the Culebra Cut Zone

Ranges	SSA (ha*)	%	ADI (ha*)	%
0 - 7%	284	2.7	249	29.2
7 - 15%	996	9.5	154	18.0
15 - 25%	2021	19.2	138	16.2
25 - 45%	6169	58.7	247	28.9
45% and greater	1045	9.9	66	7.7
Total	**10515**		**854**	

Source: URS Holdings, Inc.

Table 4-26

Distribution of Categories of Soil Use Capacity in the Culebra Cut Zone

Usage Capacity	Total Area (ha*)	%	SSA (ha*)	%	ADI (ha*)	%
III	197	1.7	121	1.2	76	8.9
IV	1157	10.2	1020	9.7	137	16.0
V	48	0.4	0	0.0	48	5.6
VI	4724	41.6	4494	42.7	230	27.1
VII	4103	36.1	4041	38.4	62	7.2
VIII	1140	10.0	839	8.0	301	35.2
Total	**11369**		**10515**		**854**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.. –Soils Studies of the Interoceanic Region of Panama.

4.3.5.6 Pacific Locks

The Pacific Locks sector includes the areas of construction of the new Pacific locks and adjoining structures, such as the water recycling basins. The Cocoli and Aguadulce Hills are found in this zone.

Table 4-27 show the categories of sloping in this zone; in the Specific Study Area there are steeper slopes, ranging between 25-45%, in approximately 46% of the area.

In the Area of Direct Impact the flatter slopes are predominant (lower than 15%), which represent 60% of the same. In these areas there have been intermittent deposits of dredged sediments from the Panama Canal modernization program. They are currently covered with thatch and have been designated as deposit sites of the Panama Canal Expansion Program. Among the deposit sites located in this zone are Victoria and Velasquez.

Table 4-27

Distribution of Slope Categories in the Pacific Locks Zone

Ranges	SSA (ha*)	%	ADI (ha*)	%
0 - 7%	249	3.8	404	35.6
7 - 15%	1309	19.7	268	23.6
15 - 25%	1696	25.5	149	13.1
25 - 45%	3069	46.2	263	23.1
45 and greater	315	4.7	53	4.6
Total	**6638**		**1137**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.

Table 4-28 shows the categories of usage capacity of the soils in the zone. In general, it is observed that the usage capacity of these soils is marginal, inasmuch as in the Specific Study Area almost 70% are Class VI or lower soils; while in the Area of Direct Impact about 50% are Class VII and VIII.

Table 4-28

Distribution of Categories of Soil Use Capacity in the Pacific Locks Zone

Usage Capacity	Total Area (ha*)	%	SSA (ha*)	%	ADI (ha*)	%
III	173	2.2	164	2.5	9	0.8
IV	1831	23.6	1651	24.9	180	15.8
V	519	6.7	204	3.1	315	27.7

Usage Capacity	Total Area (ha*)	%	SSA (ha*)	%	ADI (ha*)	%
VI	2012	25.9	1971	29.7	41	3.6
VII	2811	36.1	2525	38.0	286	25.1
VIII	429	5.5	123	1.9	306	26.9
Total	**7775**		**6638**		**1137**	

Source: URS Holdings Inc. –Soils Studies of the Interoceanic Region of Panama.

4.3.5.7 Pacific Coast

In the sector designated as Pacific Coast, the areas of Balboa, Rodman, Palo Seco, and Farfan are included. Table 4-29 presents the categories of sloping in the Pacific Coast Zone where the most outstanding elevations are the San Juan and Sosa Hills. In this zone the Amador Causeway, and the islands of Naos, Perico, and Flamenco are considered.

With regard to slopes, in the Specific Study Area there is a predominance of slopes with the range of 25-45%; whereas in the Area of Direct Impact, the ranges of slopes diminish significantly, and the predominant ones are less than 7%.

Table 4-29

Distribution of Slope Categories in the Pacific Coast Zone

Ranges	SSA (ha*)	%	ADI (ha*)	%
0 - 7%	1708	23.3	211	44.6
7 - 15%	1782	24.3	60	12.6
15 - 25%	1294	17.7	41	8.7
25 - 45%	2238	30.6	129	27.2
45 and greater	305	4.2	33	7.0
Total	**7327**		**474**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.

Table 4-30 show the categories of usage capacity of the soils in the zone. In general, it is observed that the usage capacity of these soils is marginal, in the Specific Study Area there is more variability, nevertheless, 58% of the soils are Class VI or below; in the Area of Direct Impact, around 75.10% are of the categories of marginal use, that is, Class VI, VII, and VIII.

Table 4-30

Distribution of Categories of Soil Use Capacity in the Pacific Coast Zone

Usage Capacity	Total Area (ha*)	%	SSA (ha*)	%	ADI (ha*)	%
III	816	10.5	808	11.0	8	1.8
IV	1647	21.1	1614	22.0	33	6.9
V	708	9.1	631	8.6	77	16.2
VI	1719	22.0	1528	20.9	191	40.3
VII	1327	17.0	1164	15.9	163	34.3
VIII	1584	20.3	1582	21.6	2	0.5
	7801		**7327**		**474**	

* = Values for surfaces were rounded off.

Source: URS Holdings Inc.. –Soils Studies of the Interoceanic Region of Panama.

4.4 Topography and Bathymetry

4.4.1 Methodology

The objectives in this section consist in making a description of the topographic characteristic of the base line in the six (6) zones that make up the Specific Study Area defined for the Panama Canal Widening Project, and describe the aspects related to the bathymetry in the water zones.

To this effect, an exhaustive review has been made of the existing studies about this topic, which were provided by the Panama Canal Authority. In addition, the information obtained on the 6 surfaces of the zones of the Specific Study Area as defined in this Environmental Impact Study has been compared and analyzed.

4.4.2 Topographic and Bathymetric Characteristics of the Specific Study Area

In general terms, the variable topography of the area currently occupied by the Panama Canal is basically the result of the erosion of brooks and the process of meteorization. The characteristics of the land formations are controlled by the relative resistance to rock erosion in any given area.

The region of the Area of General Study is characterized by having many cone-shaped hills, which are spaced very irregularly and, therefore, offer a somewhat chaotic appearance to the terrain. Faults and folds play a secondary role in the configuration of the view. There are well-developed and keenly defined drainage patterns, despite its comparatively recent geological age (Photographic Annex 2 - Topography - Photo 1). The valleys, in which rivers and brooks have deposited a layer of alluvial material, are areas that characteristically lay on rocks.

In areas where the sloping of the rivers and brooks are sufficiently pronounced, the brooks have carved out narrow canyons with steep sloping walls. On the other hand, in areas where the runoff goes through hard and soft formations, there is a notable widening of the valleys and a leveling of the outline of rivers and brooks.

In Graph 3-13, of Chapter 3, the topographic map for the zones in question is shown at a scale of 1;50,000. Following is a presentation of the principal features as they relate to the topography and bathymetry in each of these zones.

4.4.2.1 Atlantic Coast

The Caribbean marine zone is a secondary coastal zone, with a muddy/sandy bed (35-70% slime and clay) reaching depths of 40 meters. The seaboard is sandy, with small bays and coves such as Limon Bay and the flat terrains of the Atlantic sector, which are very low-lying lands that were formerly the estuary of the Chagres River. Dredging and drainage in the area during the construction (and widening) of the Canal and the development of the city of Colon have determined the actual outline of this bay and its surrounding areas.

Slopes in the range of 25 to 45% dominated the area, and there were elevations of up to 20 and 200 msnm[4]. The highest elevations are to be found toward the southern part of the zone, whereas the coastal zones feature lower slopes and elevations. Some elevations within the zone include Loma Borracho (60-80 meters) and Cerro Bruja (100 meters).

With regard to the bathymetry of the Atlantic Coast, soundings made as part the Study of Environmental Impact for the Expansion of the Cristobal Port (Ingemar Panama, 2005), in which 3 sites were featured as possible sites for the deposit of materials, north of the access channel, show the existence of slopes between –0.007 y – 0.013 degrees and variable depths between 24 and 51 meters. The data obtained from said bathymetries are shown in Table 4.31 and the location of the sites are shown in Graph 4-8.

Table 4-31

Bathymetries in Various Areas of the Atlantic Sector

Disposal Site	Slope (Degrees)	Minimum Depth (m)	Maximum Depth (m)
Area 1	-0.013	28	35
Area 2	-0.007	51	58
Area 3	-0.008	24	32

Source: Ingemar Panama, 2005. Prepared by URS Holdings, Inc.

Studies conducted by Panama Canal Authority of the marine deposit site for dredged materials, called the Western Breakwater[5], in the Atlantic sector, within the Area of Direct Impact of the Project, show depths between and -9 y -13.8 meters. The marine floor of same appears to be relatively uniform, with drop offs or greater depths in a Northeasterly direction (Graph 4-9).

[4] The data on elevations were obtained from the topographic map at a scale of 1:50,000 and level curves at 20-meter intervals.
[5] This deposit site is closest to the coast than the areas featured in the study of Ingemar Panama, 2005.

4.4.2.2 Gatun Locks

The topography along the mapping of the new locks has, from the north to the south, an entrance flooded by marine water, an earth dam, a sweet water lagoon (which will become part of the locks) and another earth dam adjacent to the banks of Gatun Lake.

La zona está compuesta principalmente por pendientes entre 25-45% (el 36% de la zona) y entre 0-7% (el 31% de la zona), las elevaciones varían entre los 20 y 80 msnm, observándose las mayores elevaciones en el sector sureste de la misma.

4.4.2.3 Gatun Lake

Gatun Lake, Zone 3, was formed almost a century ago by the construction of the Gatun dam that flooded the lower reaches of the rivers Chagres, Ciri Grande, Trinidad, and Gatun. The operational level of the lake is controlled by a hydraulic spillway located on the west of Gatun locks, which spills water toward the lower course of Chagres River, which in its turn spills into the Caribbean Sea. The operational level of the lake falls between a minimum of 24.8 meters (81.5') and 26.7 meters (87.5') PLD 32 for the upper level. In forming Gatun Lake, an area of 45,000 hectares was flooded. Because of the landscape of the flooded valleys, the lake is deeper on the northwest, achieving depths of 25 meters close to the Gatun Locks.

Fifty-three percent of the zone is dominated by slopes in a range of 25 – 45%, with elevations between 20 and 340 msnm. The highest elevations are those of Cerro Uraba and Cerro Balboa, both located in a southerly direction on the boundary with Zone 4. This zone is the one with the largest surface (approximately 3,555 hectares) and slopes of 45% and greater.

4.4.2.4 Culebra Cut

This section of the Specific Study Area, known as Zone 4, extends from the Pedro Miguel Locks to the confluence with Chagres Rives, at Gamboa; within this zone, 59% of its surface is dominated by slopes of 25 to 45%. Elevations vary between 40 and 300 msns, the highest of which are the hills of Tigre, Mitres, and Marieta, distributed along both sides of the navigational channel.

Along the Cut, there are several land sites, such as T2, T3/T5, and T4 (Graph 3-15), which have been designated for the deposit of dry and wet excavated material that is extracted by excavation from the banks of the Canal. Likewise, there are also other sites that received moist dredged material. These sites, for the most part, are relatively flat areas with gentle slopes, whose topography is changed, resulting from the dumping of excavated and dredged materials.

4.4.2.5 Pacific Locks

The zone that comprises Miraflores and Pedro Miguel Locks, Zone 5, includes installations connected to the operation of the Canal and the existing locks system. Said locks are separated by the artificial lake of Miraflores (2.8 kms^2), formed by the construction of a dam that spans the valley of the river Grande.

Southwest of the existing locks, is the outline or print of the proposed third set of locks. Said print is in the 1939 excavations area (which was abandoned in 1942 and is presently covered by lagoons and secondary forest). The cited abandoned excavations area include in south to northerly direction, the south entrance flooded by marine waters, an earth dam, a deep lagoon of brackish water, an intermediate earth dam, another lagoon, the north dam, fragments of a secondary forest, and an entrance to Miraflores Lake.

There are various sites in this zone for land deposits (T6, T7/Cocoli y T8/Victoria), which have been used historically and are still being used to deposit dredged (wet) or excavated (dry) material. Part of the area located to the west of the Canal is within the former Emperador firing range, in which there are still areas with unexploded duds. The T6 site located within the firing range has been designated as a land deposit for materials.

There are slopes ranging between 25 - 45% in more than 45% of the surface of this zone, whereas elevations vary between 20 and 220 msnm. The most prominent elevation is Santa Cruz hill, located west of the plot that is the T6 site. Within this zone there are also other hills such as Paraiso (Cartagena), Aguadulce, and Cocoli.

4.4.2.6 Pacific Coast

This zone has an extensive coastal area to include industrialized or urban port areas.

Thirty-one percent of the zone is dominated by slopes between 25 – 45%, and 24% of the zone has relatively low slopes, between 7 and 15%. Elevations vary between 20 and 206 meters, among which Cerro Ancon and Sierra Miñon are the hightest.

With regard to the bathymetry of the zone, according to studies and records of the ACP, it is known that the approaches to the entry of the Canal have been dredged to 16.49 meters below PLD[6]. Other studies carried out in the Rodman port area show depths between 3.1 and 12.2 meters and point to modification of the marine floor as a result of the constant sedimentation of the hydrograph network materials, as well as by continual sedimentation owing to erosion phenomena on the land mass (REA Consulting, 2002).

ACP Studies of the marine sites of Palo Seco, Tortolita, and Tortolita South, in the Pacific Sector, for deposit of dredged material, show depths between 0.2 and 13.6 meters. The maximum depth recorded for Palo Seco, was 2.25 meters (Graph 4-10). Concerning the Tortolita deposit site, the marine floor of this site show a fairly uniform pattern of depths, with some peaks that divide the site into two parts, and maximum depths of around 11 meters (Graph 4-11). The Tortolita South site has depths of 10 to 13.6 meters, the bottom is uniformly distributed with a tendency to a slight decline in a north to south direction (Graph 4-12).

Concerning the behavior of these sites over a long period, the following has been gleaned from the comparative analysis of changes in the bathymetry of these sites for the period of 1998 to 2006 as reported in the Environmental Impact Study for the Widening and Deepening of the Access Channel to the Pacific Entrance of the Panama Canal:

[6] PLD = Precise Level Datum and approximates mean sea level.

- Palo Seco: Very small changes, most of which fall within –0.25 m y 0.25 m, in a normal distribution of around 0, a maximum value of 2.21 m (addition) and a minimum value of –0.62 m (erosion). The minimum changes at the level of the floor are associated in that the area was not used in the period in which the comparison was made. The compared data are for the years 2003-2006.

- Tortolita: Significant changes most of which are within +1 m with extreme values of –3.95 m and 4.59 m and a median of 0.25 m which reflects a small average decrease in the depths. The changes observed may reflect or may be considered attributable to the local impact associated to the low level deposit activity. The comparison data are for the years 2002-2006.

- Tortolita South: Significant changes that reflect the accumulation of a large mound of material throughout the entire deposit site, and having large areas that show a loss of depth of more than 2 meters. Variations range between 0 and 2.5 meters. This change in the site may be attributed to its use between the years of 2002 and 2006 by the canal modernization program. Comparison data are for the years 1998 – 2005.

4.5 Climate

It is of vital importance to make a recognizance of the climatic conditions within the Specific Study Area to be able to make a general interpretation of the environmental conditions of the area and its influence during the implementation of the Project. In this section, the main climatic characteristics are presented for the zone in which the Panama Canal expansion works will be developed.

4.5.1 Methodology

In developing this section, a review has been conducted of prior studies undertaken by ACP, and the analysis has been made of the climatic data of some stations conforming the network of hydro meteorological stations of the Panama Canal Authority (ACP), located in the proximities of the Specific Study Area.

The cited stations from which references were utilized are the Type A stations that provide the most complete meteorological information for this type of analysis. Emphasis was placed on the stations located in the representative zones of the Specific Study Area, that is, the Limon Bay Station in the Atlantic Coast Zone; the Gamboa Station in the Gatun Lake Zone; and the Balboa Station in the Pacific Coast Zone. Owing to the relatively slight spatial variability of the climatic variables from one zone to the next within the Specific Study Area, it was considered sufficient for an adequate characterization to utilize the data of three of the zones that represent climatic conditions present in the extreme en sections (Atlantic and Pacific) and in one intermediate section of the area of study.

Graph 4-13 shows the location of the Hydro meteorological Stations considered in this analysis, and Table 4-32 describes the main characteristics of said stations.

Table 4-32

Hydrometeorological Stations Considered for Climate Study

Nº	Name	Elevation (m)	UTM Coordinates		Type of Station	Parameters	River, Lake or Sea
			X	Y			
4	Gamboa	31.4	643528.95	1007454.88	Principal (Type A) / Limnic	ML	Gatun
26	Balboa FAA	10.1	659468.14	991664.02	Principal (Type A)	M	_
31	Limon Bay	3.05	619176.66	1034280.22	Principal (Type A) / tidal	MLT	Atlantic
M = Meteorological (rainfall; air temperature; wind velocity, direction, and gust; relative humidity; solar radiation, and barometric pressure), L = Lake Level or Tide T = Temperature.							

Source: ACP Hydrologic Yearbook. 2005.

For the stations studied, the information used was for a 10-year recording period, from 1996 to 2005[7]. The Panama Canal Authority Meteorology Section supplied the data for this analysis.

4.5.2 Characterization of Climate

For purposes of characterizing the climate, the following have been selected as the basic variables for description: rainfall, temperature, relative humidity, wind velocity and direction, solar radiation, and evapo/transpiration.

4.5.2.1 Types of Climates

According to the classification system of Köppen , there are three types of climates in the Area of General Study: Very Humid Tropical Climate, Humid Tropical Climate, and Tropical Climate of the grassy lands, the latter located in the Pacific sector of the Canal watershed (Graph 4-13), as is described below:

- **Very Humid Tropical Climate (Afi)**: Found to a limited extent at the northeast and northwestern end of the Area of General Study. This type of climate is characterized by copious rainfall throughout the entire year. During the driest month (February), rainfalls are usually more than 60mm, the median temperature of the coolest month (November) is above 18ºC, and the difference between the median temperature of the hottest month (August) and the coolest month is lower than 5ºC.

- **Humid Tropical Climate (Ami)**: Found along the entire Area of General Study, covering the entire surface of the Atlantic Area and a large part of the Pacific sector. Approximate 90% of the Area of General Study is influence by this type of climate, characterized by an annual rainfall greater of 2,500 mm, a marked dry season that lasts 3 months (January to March) and an annual average temperature ranging between 24 ^{o}C and 26 ^{o}C.

[7] Data Registry at the Limon Bay Station began in large part as of 2001.

- **Tropical Grass Lands Climate (Awi):** Found in the Pacific sector of the Area of General Study. It is characterized by annual rainfalls below 2,500 mm, prolonged dry season (between the months of January or March), the median temperature of the coolest month (November) 18ºC, and the difference between the median temperature of the hottest month (April) and the coolest is less than 5ºC.

4.5.2.2 Precipitation

The annual average precipitation registered at ACP stations within or near the Specific Study Area (Limon Bay, Gamboa and Balboa FAA) varies from 1891.3 mm and 2786.7 mm; the lowest value was to be found at the Balboa FAA Station and the hightest at the Limon Bay Station. Table 4-33 and Graph 4-1 show the annual variation values at each station.

Table 4-33
Annual Rainfall
(mm)
1996 – 2005 Period at Indicated Stations

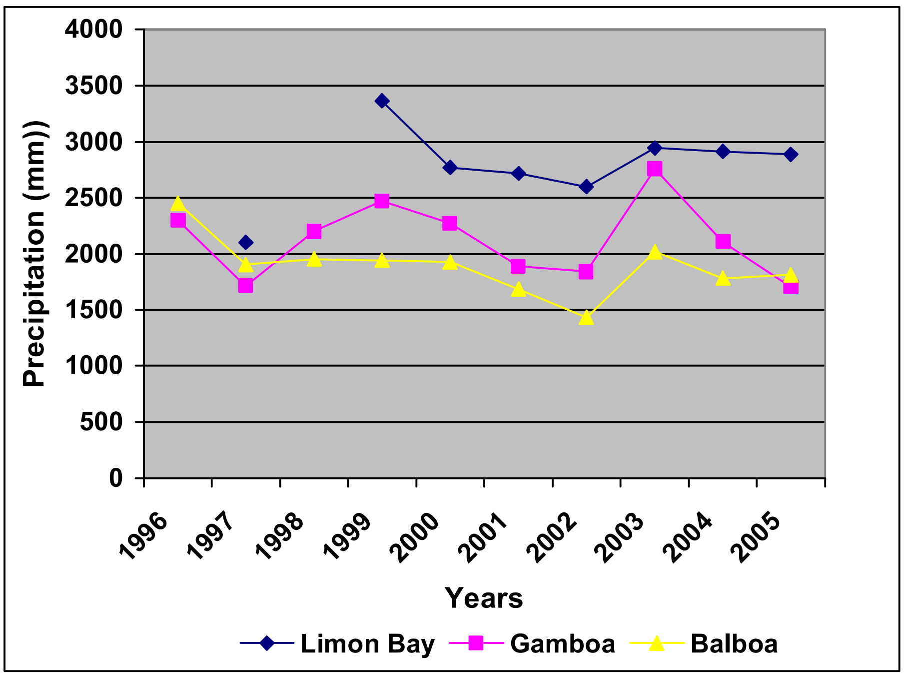
Year	Limon Bay	Gamboa	Balboa FAA
1996	---	2298.7	2451.1
1997	2100.6	1714.5	1905.0
1998	---	2199.6	1953.3
1999	3363.0	2468.9	1940.6
2000	2771.1	2270.8	1927.9
2001	2717.8	1887.2	1684.0
2002	2595.9	1841.5	1435.1
2003	2943.9	2761.0	2019.3
2004	2913.4	2108.2	1783.1
2005	2888.0	1704.3	1813.6
Average	2786.7	2139.60	1891.3

Souirce: URS Holdings, Inc., with data provided by ACP.

Graph 4-1

Annual Precipitation

Period 1996 – 2005



Source: URS Holdings, Inc., with data provided by ACP.

This data show the typical characteristics of the region, toward the Atlantic (Limon Bay) the climate is humid with greater precipitations, whereas for the Pacific (Balboa FAA) the climate is drier with considerably less precipitations. Upon analyzing the data in the Table and the Graph shown above, it was observed that the year 1997 was the driest in the Gatun and Atlantic sectors, with annual precipitations of close to 75% and 80% of the annual median, respectively. This condition was influenced by the presence of the El Niño Phenomenon in Panama at that time (1997 – 1998), which is characterized by bringing with it periods of droughts. Again, in the years 2002 – 2003, the presence of said climatic phenomenon was felt in Panama, this time with greater intensity in the Pacific sector, where the annual precipation for 2002 barely reached close to the 76% annual median, even though its intensity in other sectors were relatively less severed than in the preceding period.

Table 4-34 and Graph 4-2 show the median monthly values of the three stations analyzed and referenced above, as an average of the 10-year period of 1996 and 2005.

Table 4-34

Average Monthly and Average Annual Rainfall (mm)

For the 1996 –2005 Period

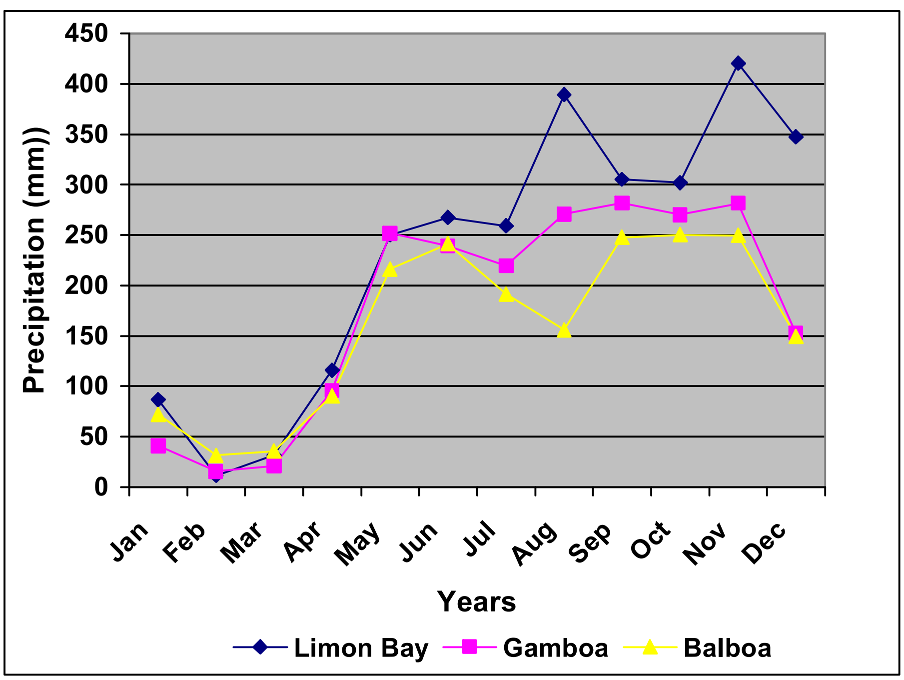
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Limon Bay	86.7	11.4	31.4	115.9	250.2	267.3	259.1	389.3	305.4	301.9	420.4	347.7	2786.7
Gamboa	40.9	15.5	20.8	95.4	251.9	239.0	219.6	270.9	281.5	270.2	281.2	152.9	2139.6
Balboa	72.0	31.4	35.5	90.3	216.4	241.3	191.5	155.9	247.6	250.2	249.7	149.6	1931.4

Source: URS Holdings, Inc., with data provided by the ACP

Graph 4-2

Monthly Average Precipitation (mm)

Period 1996 – 2005



Source: URS Holdings, Inc., with data provided by ACP

In general terms, a considerable increase may be observed in the average monthly precipitation for the months of May to December, compared to the levels of precipitation for the months of January to April, coinciding with the typical rainy season and dry season of the country.

It is worthwhile noting that the operation of the Panama Canal depends wholly on the rains that fall into the Watershed (3,360 kms^2). The dry season (4 months long), is characterized by the lack of rains resulting from the action of the tradewinds and the movement of the Intertropical Zone of Convergence on the Isthmus. The rainfall schedule of the Watershed is influenced by the Intertropical Zone of Convergence, which is responsible for the two climatic seasons in Panama.

4.5.2.3 Temperature

The behavior of the environmental temperature shows few fluctuations throughout a ten-year recording period (1996 – 2005), according to the date from the Panama Canal Authority stations of Limon Bay, Gamboa, and Balboa FAA shown in Tables 4-35 and 4-36.

Table 4-35
Average Annual Temperature (ºC)
For the 1996 –2005 Period at Indicated Stations

Year	Limon Bay	Gamboa	Balboa
1996	--	25.8	26.0
1997	--	26.7	26.8
1998	--	26.7	27.1
1999	--	25.7	26.0
2000	--	25.8	26.1
2001	27.3	26.1	26.3
2002	27.3	26.7	27.1
2003	26.6	25.9	26.8
2004	26.4	26.0	27.0
2005	26.8	26.7	27.5
Average	26.9	26.2	26.7

Source: URS Holdings, Inc., with data provided by the ACP

The annual average temperature at the Limon Bay Station reached an average value of 26.9ºC, the high being 27.3ºC for the year 2001, and the low 26.4ºC for the year 2004. For its part, the

Gamboa Station shows an annual average temperature of 26.2ºC, which ranges between a high of 26.7 ºC for the years 1997, 1998, 2002, and 2005 and a low of 25.7ºC for the year 1999. Lastly, the Balboa FAA station registered an average annual temperature of 26.7ºC, with highs of 27.5ºC during the year 2005 and lows of 26.0ºC for years 1996 and 1999 (Table 4-35). Only very slight differences in temperatures are observed among the three stations.

At the Limon Bay Station, the average monthly temperatures ranged between 26.4°C and 27.1°C, with the highest temperatures occurring during the dry season and the lowest during the rainy season. At the Gamboa Station the average monthly temperatures ranged between 25.6 to 27.0°C, with the month of November being the coolest on average, while the month of April was the hottest (Table 4-36). Similar conditions to those registered at the Limon Bay and Gamboa stations are present at the Balboa FAA Station. In conclusion, it may be noted in Table 4-36 that, as far as extreme conditions (highs and lows) are concerned, the months of March and April show the most elevated records of high temperature, coinciding with scarce precipitation; while the months of October and November register the lowest temperature averages, coinciding with the rainy season.

Table 4-36

Monthly Average, Median High, and Median Low Temperatures (°C)

For the 1996-2005 Period

Stations	Limon Bay			Gamboa			Balboa		
Month	Average	High	Low	Average	High	Low	Average	High	Low
Jan	26.8	27.4	26.2	26.0	27.2	24.8	26.5	28.3	25.5
Feb	26.7	27.2	25.9	26.3	27.7	25.0	27.0	27.9	26.1
Mar	27.0	27.5	26.7	26.6	28.1	25.7	27.5	28.6	26.5
Apr	27.1	27.5	26.7	27.0	28.6	26.1	27.7	28.4	27.0
May	27.1	27.5	26.5	26.7	28.1	25.6	27.1	27.9	26.2
Jun	27.1	28.1	26.3	26.4	27.7	25.6	26.6	27.1	25.8
Jul	27.0	27.8	26.1	26.0	27.6	25.1	26.5	27.3	26.0
Aug	27.1	28.3	26.1	26.1	27.5	25.1	26.5	27.3	25.8
Sep	26.8	27.4	26.1	25.8	27.6	24.8	26.2	27.0	25.3
Oct	26.8	27.9	26.1	25.8	26.9	24.7	26.2	26.7	25.5
Nov	26.4	27.2	25.5	25.6	27.1	24.6	25.9	26.6	25.3
Dec	27.0	27.7	25.9	25.9	27.0	24.7	26.0	27.3	25.6
Average	**26.9**	**27.3**	**26.4**	**26.1**	**27.5**	**25.1**	**26.6**	**27.5**	**25.8**

Source: URS Holdings, Inc., with data provided by the ACP

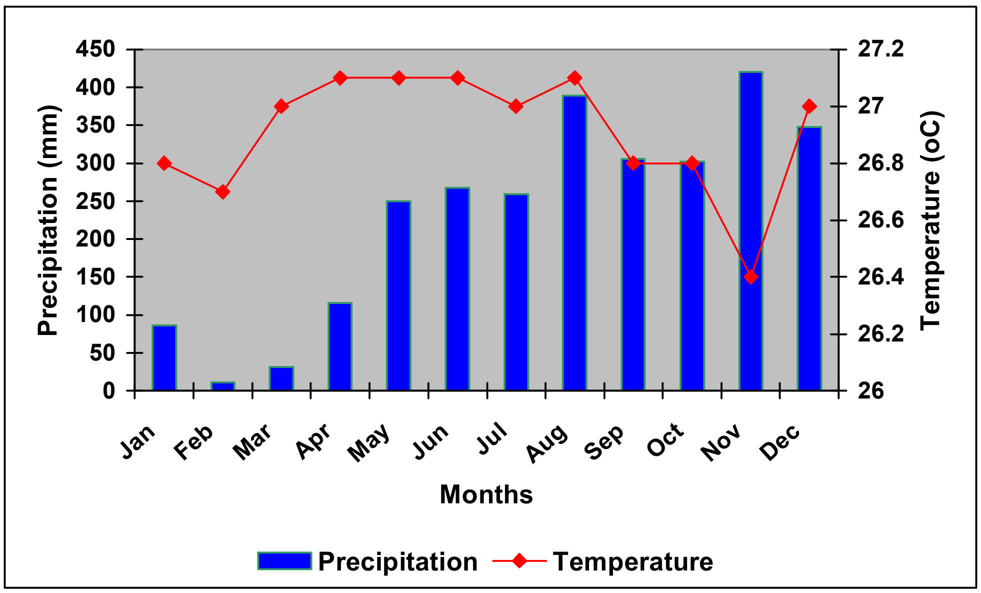
Temperature and precipitation bear a direct relation to variables, observing, based on monthly averages for both parameters, that in the period of 1996 to 2005 the same are inversely proportional, particularly for the months of November to February. That is, to a greater rainfall, there is a lower temperature and vice versa; this may be seen in Graphs 4-3, 4-4, and 4-5 at the Limon Bay, Gamboa, and Balboa FAA stations as shown below:

Graph 4-3

Average Monthly Precipitation and Temperature

Registered at Limon Bay Station

Period 1996 – 2005



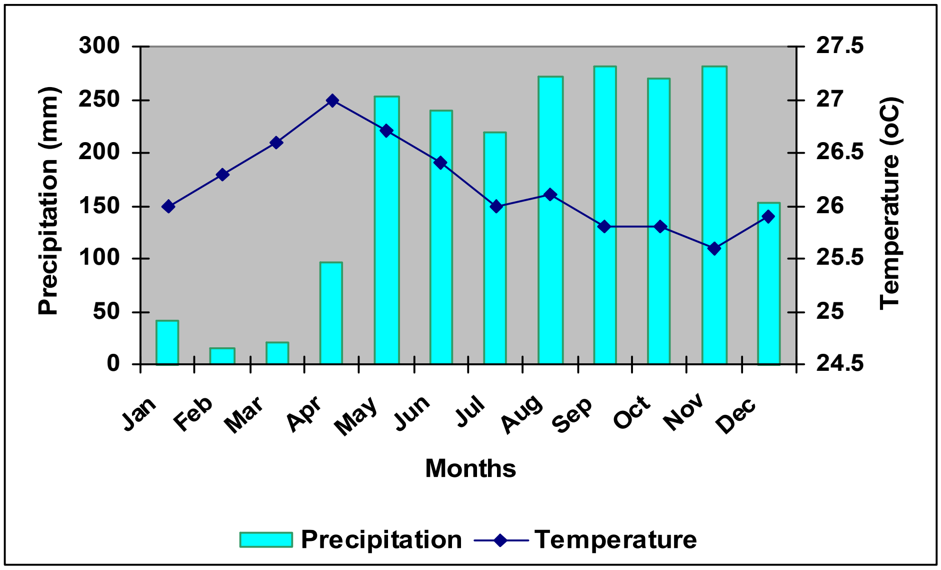
Source: URS Holdings, Inc., with data provided by the ACP

Graph 4-4

Average Monthly Precipitation and Temperature

Registered at Gamboa Station

For the 1996 – 2005 Period



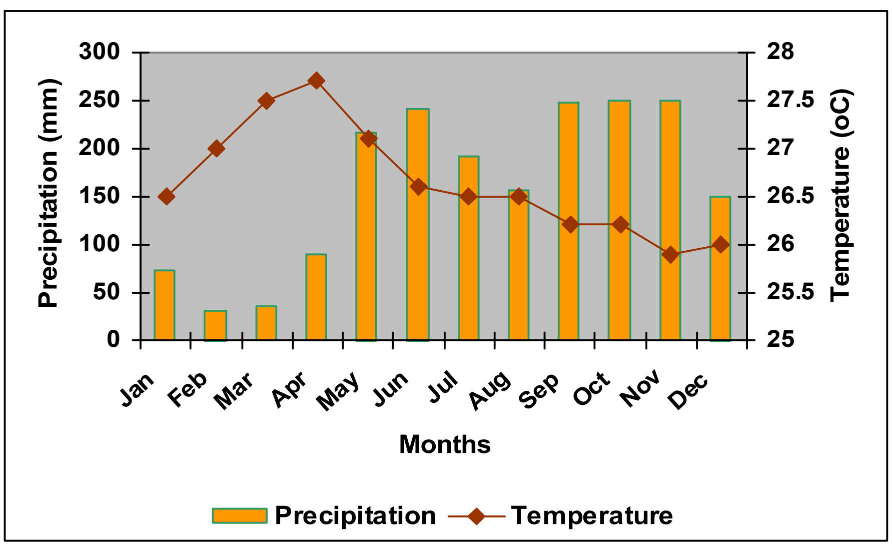
Source: URS Holdings, Inc., with data provided by the ACP

Graph 4-5

Average Monthly Precipitation and Temperature

Registered at Balboa FAA Station

For the 1996 – 2005 Period



Source: URS Holdings, Inc., with data provided by the ACP

4.5.2.4 Relative Humidity

Relative humidity is closely related to precipitation and, in general terms, is directly proportional: that is, the greater the precipitation the higher the relative humidity, and vice versa.

This relation may be seen in the Limon Bay Station data (Table 4-37), where it shows that the lowest relative humidity was registered during the first few months, i. e., during the dry season and these ranged between 83.1 and 85.6%. Meanwhile, the more elevated values of relative humidity were documented in the months of the rainy season, registering between 89.5 and 99.3%.

Table 4-37
Average Monthly and Annual Relative Humidity (%)
Limon Bay Station
For the 2001-2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avrg.
2001	85.0	83.8	85.1	86.2	87.7	87.8	89.6	89.8	89.3	89.6	90.2	86.2	**87.5**
2002	87.4	84.6	86.1	86.5	89.4	90.2	91.2	99.3	99.0	99.1	92.4	85.0	**90.9**
2003	83.1	84.1	83.6	85.6	89.9	90.4	91.1	90.7	89.7	90.1	91.5	89.5	**88.3**
2004	84.6	84.4	85.3	87.5	89.7	89.9	90.3	91.3	92.7	92.5	90.5	86.7	**88.8**
2005	87.3	85.6	86.8	87.6	91.4	91.8	89.8	92.5	96.3	94.1	91.1	83.1	**89.8**
Avrg.	**85.5**	**84.5**	**85.4**	**86.7**	**89.6**	**90.0**	**90.4**	**92.7**	**93.4**	**93.1**	**91.1**	**86.1**	**89.0**

Source: URS Holdings, Inc., with data provided by the ACP

As stated before, the months with the lower relative humidity are those marked by the dry season, for which these parameters at the Gamboa Station fluctuate between 65.7 and 70.2%; meanwhile, the months of the rainy season show higher averages of relative humidity which fluctuate between 91.4 and 97.4% (Table 4-38).

Table 4-38

Average Monthly and Annual Relative Humidity (%)

Gamboa Station

For the 1996-2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avrg.
1996	82.1	78.6	76.1	78.0	79.9	82.2	83.3	84.8	84.8	78.3	84.7	81.0	**81.1**
1997	78.5	73.9	68.0	68.6	77.3	82.7	81.0	81.6	81.1	80.3	80.5	73.4	**77.2**
1998	70.2	69.0	65.7	68.7	74.5	77.0	76.8	76.5	74.1	73.2	74.4	84.8	**73.7**
1999	76.1	71.6	70.6	72.5	78.5	86.8	79.3	76.6	74.9	73.1	72.9	75.7	**75.7**
2000	84.8	78.0	73.7	77.7	86.0	88.4	86.0	77.1	85.3	86.2	84.5	84.6	**82.7**
2001	81.6	78.6	79.2	77.8	82.1	84.4	85.8	84.3	82.9	82.5	82.0	82.5	**82.0**
2002	78.0	74.8	75.2	76.0	77.4	82.0	82.5	82.7	82.4	82.4	82.4	78.1	**79.5**
2003	75.2	74.5	73.5	76.7	82.1	82.1	84.3	84.3	84.4	94.0	85.5	83.7	**81.7**
2004	88.1	84.9	82.8	87.0	91.1	91.6	94.4	96.3	97.1	97.0	95.9	95.5	**91.8**
2005	86.3	83.1	85.3	86.2	91.4	91.1	91.6	91.5	92.5	96.6	97.4	95.4	**90.7**
Avrg.	**80.1**	**76.7**	**75.0**	**76.9**	**82.0**	**84.8**	**84.5**	**83.6**	**84.0**	**84.4**	**84.0**	**83.5**	**81.6**

Source: URS Holdings, Inc., with data provided by the ACP

Concerning the Balboa FAA Station, the analysis of relative humidity at this site shows results similar to those obtained for the Limon Bay and Gamboa stations where the lowest relative humidity is registered during the first few months of the year within a range of 64.9 to 70.5%. While the highest values were registered during the months of the rainy season, with values ranging frm 88.8 to 93.8% (Table 4-39).

Table 4-39

Average Monthly and Annual Relative Humidity (%)

Balboa Station

For the 1996-2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avrg.
1996	80.2	75.2	72.8	74.2	83.7	85.3	83.6	84.0	84.9	84.1	83.2	80.0	80.9
1997	75.3	72.3	66.1	69.3	77.3	83.5	82.5	82.7	85.2	85.2	85.4	75.9	78.4
1998	70.5	70.2	64.9	70.9	81.1	84.6	84.3	84.7	82.5	82.8	84.3	85.4	78.9
1999	76.2	70.7	69.9	75.3	82.2	84.2	83.0	84.1	82.5	82.9	83.3	82.7	79.8
2000	73.7	68.8	65.4	69.8	80.4	83.0	81.8	81.7	82.7	82.8	81.7	80.3	77.7
2001	74.7	70.9	71.6	70.5	77.9	80.3	80.7	80.6	82.4	82.5	82.2	82.2	78.0
2002	77.3	72.8	72.0	74.9	74.7	77.4	81.3	81.9	82.8	83.3	82.9	79.2	78.4
2003	74.2	72.0	73.2	73.8	82.5	84.4	83.2	83.6	83.6	85.1	85.4	81.7	80.2

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avrg.
2004	82.5	78.8	75.3	80.0	86.0	88.8	92.2	93.8	92.5	93.4	93.2	88.2	87.1
2005	80.7	76.1	80.1	83.3	89.1	88.2	89.0	91.6	93.2	92.9	92.5	88.5	87.1
Avrg.	**76.5**	**72.8**	**71.1**	**74.2**	**81.5**	**83.9**	**84.1**	**84.8**	**85.2**	**85.5**	**85.4**	**82.4**	**80.6**

Source: URS Holdings, Inc., with data provided by the ACP

Data from the three Stations show that relative humidity was lower during the first few years. At the Gamboa and Balboa FAA stations, it was the year 1998; at the Limon Bay station, for which there are only five (5) years of records, it was the year 2001. Records of the highest relative humidity at the Gamboa and Balboa FAA stations coincide in the years 2004 and 2005, while the Limon Bay station records showed the highest relative humidity in the years 2002 and 2005 (Tables 4-37, 4-38 y 4-39).

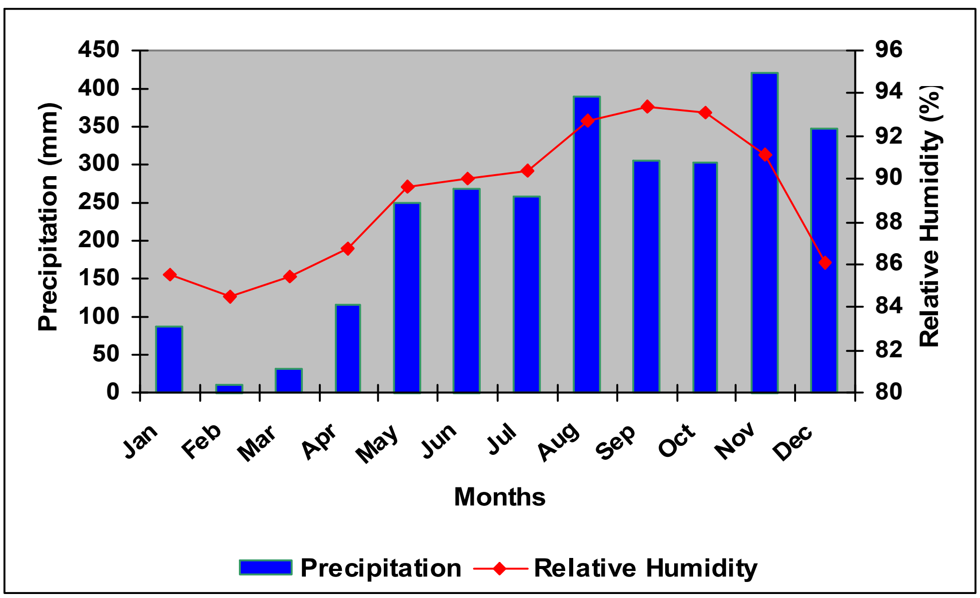
Graphs 4-6, 4-7, and 4-8 show the existing relation of the monthly precipitation averages and the average monthly relative humidity for the Limon Bay, Gamboa, and Balboa FAA, respectively.

Graph 4-6

Average Monthly Precipitation and Relative Humidity

Limon Bay Station

For the 2001 – 2005 Period



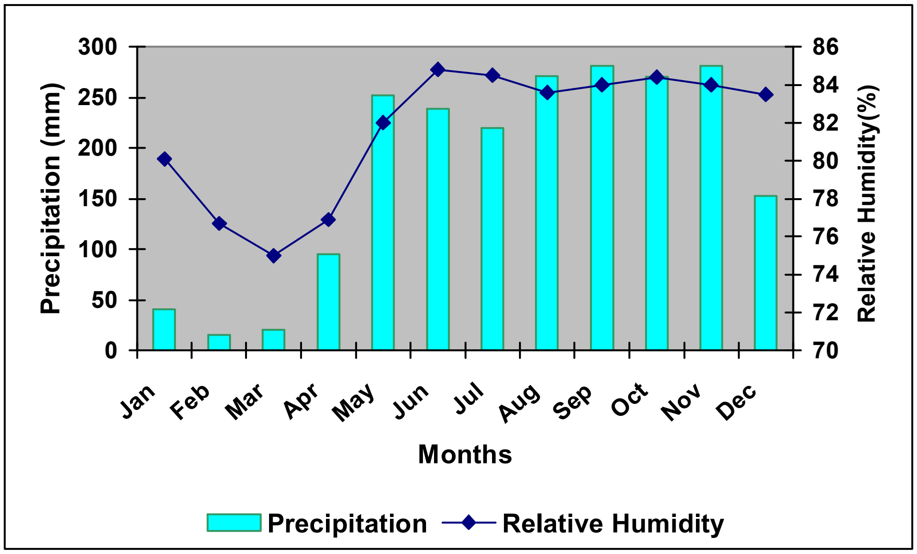
Source: URS Holdings, Inc., with data provided by the ACP

Graph 4-7

Average Monthly Precipitation and Relative Humidity

Gamboa Station

For the 1996 - 2005 Period



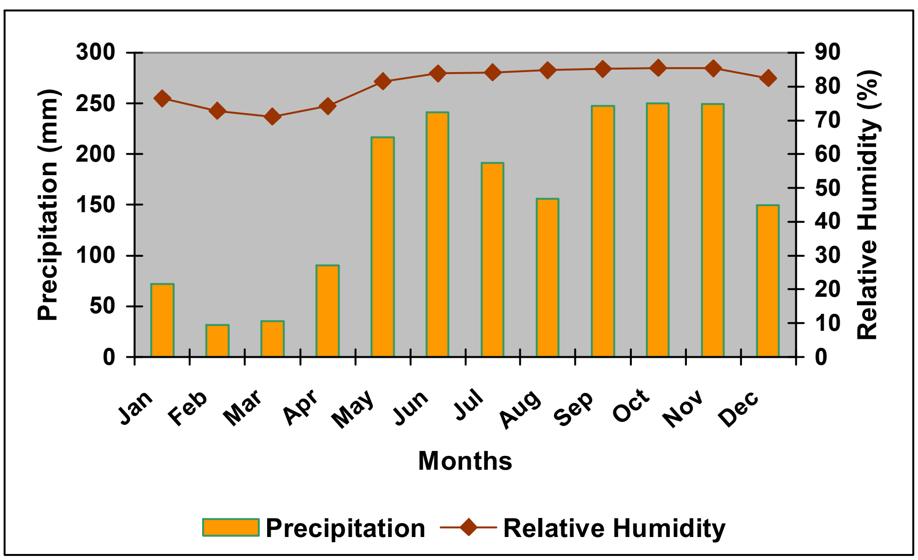
Source: URS Holdings, Inc., with data provided by the ACP

Graph 4-8

Average Monthly Precipitation and Relative Humidity

Balboa Station FAA

For the 1996 – 2005 Period



Source: URS Holdings, Inc., with data provided by the ACP

4.5.2.5 Wind Velocity

For a recording period of five years (2001-2005), the Limon Bay Station shows relatively high average wind velocities, with intensities throughout the year that range from 11.7 km/hr in the month of September up to 28.8 km./hr in February. The highest wind velocities are recorded in the first few months of the year (January, February, March, and April), whereas they begin to slow down as the rainy season begins, that is, the months of May to December (Table 4-40).

On the other hand, the average monthly wind velocities measured at the Gamboa Meteorological Station are of moderate intensity, with a maximum during the dry season that throughout the year oscillate between average velocities of 2.9 to 7.0 km/hr. and the highest average velocity has been recorded during the month of March. As may be seen in Table 4-41, the months of January through April are the ones in which are recorded the highest average wind velocities, which coincides, characteristically, with the dry season.

Concerning the Balboa FAA, the maximum average winds are likewise shown during the dry season, with an average velocity that fluctuated between 5.4 and 8.7 km./hr over a period of 10 years (1996 – 2005), coinciding with the Gamboa Station in the month of March as the one with the highest average velocity (Table 4-42). The months that registered the highest wind velocity averages were the months from January to April (Table 4-42), which is typical of the dry season.

Table 4-40

Average Wind Velocity (km/hr)

Limon Bay Station

For the 2001 – 2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avrg.
2001	27.0	32.5	23.8	29.1	16.1	18.5	15.4	15.6	12.4	13.4	15.6	16.7	19.7
2002	26.9	30.4	29.8	28.0	22.0	12.4	15.8	16.7	11.3	12.2	16.4	23.0	20.4
2003	27.2	25.6	23.3	19.3	13.7	11.6	12.4	14.0	11.1	11.1	12.6	20.1	16.8
2004	26.1	26.9	32.2	23.2	17.1	14.0	13.2	13.4	11.1	11.6	14.8	23.8	18.9
2005	29.5	28.8	19.2	20.0	12.1	11.4	13.2	12.9	12.7	13.4	15.3	19.0	17.3
Avrg.	**27.3**	**28.8**	**25.7**	**23.9**	**16.2**	**13.6**	**14.0**	**14.5**	**11.7**	**12.3**	**14.9**	**20.5**	**18.6**

Source: URS Holdings, Inc., with data provided by the ACP

Table 4-41

Average Wind Velocity (km/hr)

Gamboa Station

For the 1996 – 2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avrg.
1996	6.3	7.7	7.7	6.2	3.6	3.7	3.9	3.7	3.2	3.4	5.5	4.6	5.0
1997	5.7	7.6	8.4	6.6	5.3	3.5	4.5	5.4	3.9	3.0	4.8	4.8	5.3
1998	6.0	5.6	7.5	6.5	4.3	3.2	3.6	3.3	2.5	3.0	4.8	4.0	4.5
1999	4.5	6.0	6.4	5.3	3.2	2.7	3.9	2.6	2.3	2.6	4.1	3.9	4.0
2000	5.0	5.1	5.1	4.8	3.5	3.4	4.2	3.2	2.7	4.3	7.0	5.0	4.5
2001	4.8	6.9	7.4	6.6	5.1	4.0	4.0	4.3	3.2	3.2	5.2	5.0	5.0
2002	5.1	6.1	6.0	6.3	4.8	3.4	4.2	4.3	2.7	2.1	3.4	4.7	4.4
2003	6.6	7.7	7.1	5.8	4.0	2.9	3.7	4.3	3.1	2.6	4.1	4.5	4.7
2004	5.5	7.2	9.0	6.1	4.3	4.2	4.2	4.0	2.9	2.3	3.6	4.3	4.8
2005	5.5	7.9	5.8	6.0	3.4	2.4	2.6	3.1	2.9	2.6	4.1	3.4	4.1
Avrg.	**5.5**	**6.8**	**7.0**	**6.0**	**4.2**	**3.3**	**3.9**	**3.8**	**2.9**	**2.9**	**4.7**	**4.4**	**4.6**

Source: URS Holdings, Inc., with data provided by the ACP

Table 4-42

Average Wind Velocity (km/hr)

Balboa Station

For the 1996 – 2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avrg.
1996	5.0	6.1	6.7	5.8	3.4	4.0	4.2	4.3	4.0	5.4	6.5	5.2	5.1
1997	6.4	6.6	8.4	8.3	7.1	5.6	6.5	6.9	5.4	4.8	5.4	8.3	6.6
1998	8.8	7.7	9.4	7.8	6.3	5.5	5.9	5.8	5.7	6.4	4.6	4.7	6.5
1999	5.1	7.4	7.7	6.9	5.5	5.3	6.4	5.6	6.0	6.0	6.1	6.6	6.2
2000	6.1	6.8	6.8	7.4	6.3	5.6	6.3	6.0	5.5	6.6	5.3	6.9	6.3
2001	8.7	10.6	9.8	9.2	7.2	5.5	6.3	6.6	5.3	5.3	6.9	6.6	7.3
2002	8.0	9.5	9.7	6.9	8.0	6.6	5.8	6.4	4.8	5.3	5.5	7.2	7.0
2003	10.6	9.8	9.0	8.2	6.1	5.8	5.5	6.9	5.1	4.8	5.6	5.5	6.9
2004	7.2	8.9	10.1	8.2	6.8	6.4	6.4	6.9	6.3	5.3	6.3	7.6	7.2
2005	8.2	10.5	9.0	9.0	6.8	5.6	5.5	6.8	6.1	6.9	7.1	6.4	7.3
Avrg.	**7.4**	**8.4**	**8.7**	**7.8**	**6.4**	**5.6**	**5.9**	**6.2**	**5.4**	**5.7**	**5.9**	**6.5**	**6.7**

Fuente: URS Holdings, Inc con datos proporcionados por la ACP.

With regard to the highest wind velocity, the Limon Bay Station shows velocities that in the month of October reach an average of up to 63.2 km/hr. During the five recording years, it was shown that in August 2001 the wind velocity reached 77.1 km/hr (Table 4-43). Maximum velocities registered at the Gamboa Station, on average reached up to 41.1 km/hr during the month of March; nevertheless, the maximum wind velocity registered was for May 2000, when they reached 70.5 km/hr (Table 4-44). The highest average as far as maximum velocity at the Balboa Station was in the month of March, with 42.7 km/hr (Table 4-45). However, the month of July 2004 records the maximum wind velocity achieved at 61.8 km/hr (Table 4-45).

Table 4-43

Maximum Wind Velocity (km/hr)

Limon Bay Station

For the 2001 – 2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
2001	65.2	61.3	55.2	58.4	65.5	50.9	64.1	77.1	58.4	72.9	64.5	69.0	63.5
2002	55.8	64.1	54.1	57.6	58.7	55.8	58.6	53.1	56.5	67.9	57.0	58.3	58.1
2003	57.8	53.4	48.6	54.7	51.2	46.8	48.1	45.9	52.3	43.1	57.3	59.9	51.6
2004	64.9	62.9	57.1	53.3	64.4	61.3	55.7	67.4	52.8	73.9	55.7	63.6	61.1
2005	66.3	56.8	49.7	54.1	48.8	64.1	55.5	55.7	51.3	58.3	59.5	53.8	56.2
Average	**62.0**	**59.7**	**52.9**	**55.6**	**57.7**	**55.8**	**56.4**	**59.8**	**54.3**	**63.2**	**58.8**	**60.9**	**58.1**

Source: URS Holdings, Inc., with data provided by the ACP

Table 4-44

Maximum Wind Velocity (km/hr)

Gamboa Station

For the 1996 – 2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1996	45.2	46.7	39.6	35.2	44.1	33.5	34.6	30.3	32.3	34.6	43.1	40.6	38.3
1997	40.2	44.1	45.5	40.2	39.1	38.5	46.3	39.9	31.4	31.4	33.8	42.3	39.4
1998	41.7	35.2	41.7	38.8	35.9	35.6	33.5	34.1	42.6	37.3	33.2	30.3	36.7
1999	34.6	36.4	43.5	38.1	45.9	33.2	32.0	29.9	29.6	35.9	32.0	42.3	36.1
2000	44.1	40.6	44.6	35.6	70.5	30.9	31.7	36.4	26.7	31.9	29.3	32.8	37.9
2001	35.2	42.5	36.2	35.2	34.9	27.7	32.3	30.4	32.3	31.7	28.8	29.5	33.1
2002	29.9	33.8	39.9	35.6	32.0	35.2	33.6	35.1	35.1	27.2	42.2	31.7	34.3
2003	35.7	41.2	40.9	38.1	30.1	32.8	30.9	34.4	51.2	30.1	32.5	35.2	36.1
2004	43.1	41.0	43.5	36.5	29.9	33.5	30.4	34.8	27.0	29.1	36.2	31.7	34.7
2005	33.2	41.5	35.4	32.3	31.7	29.5	29.9	29.3	27.0	25.6	30.3	30.9	31.4
Average	**38.3**	**36.1**	**41.1**	**36.6**	**39.4**	**34.0**	**33.5**	**33.4**	**33.5**	**31.5**	**34.1**	**34.7**	**35.8**

Source: URS Holdings, Inc., with data provided by the ACP

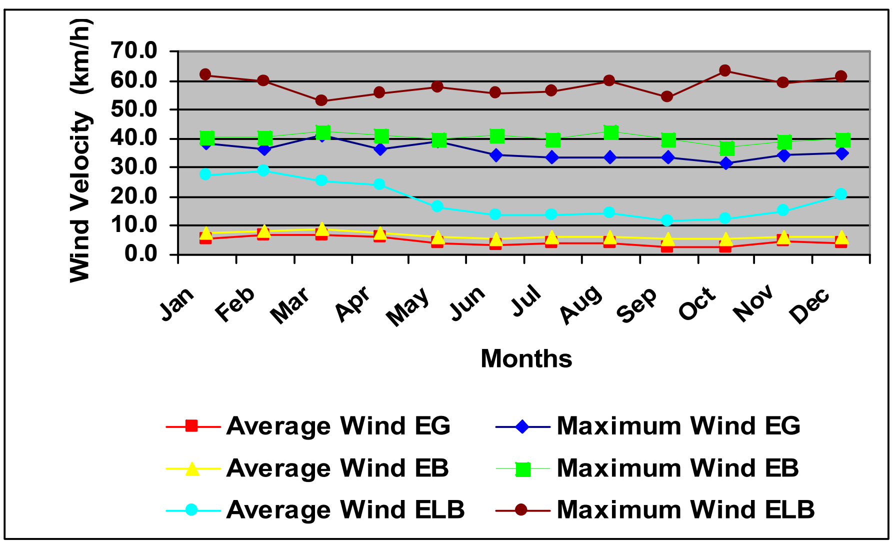
Table 4-45
Maximum Wind Velocity (km/hr)
Balboa FAA Station
For the 1996 – 2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1996	40.2	38.1	49.6	38.5	34.1	34.9	38.1	34.6	31.7	37.3	38.5	34.1	37.5
1997	35.9	37.0	42.3	40.2	36.7	42.6	46.7	48.4	47.3	33.5	39.1	45.2	41.3
1998	43.5	40.6	48.4	49.1	39.9	48.4	37.3	41.7	35.6	44.6	37.8	37.0	42.0
1999	37.8	40.2	39.9	39.6	33.8	35.9	37.3	34.6	34.9	42.3	34.6	43.8	37.9
2000	53.8	40.6	40.2	42.6	43.5	35.2	40.9	53.6	45.2	37.2	40.4	39.9	42.8
2001	39.1	41.7	41.0	39.4	38.6	49.1	35.9	46.5	47.3	35.9	35.6	39.3	40.8
2002	36.7	40.9	39.4	45.7	35.2	43.3	34.0	40.2	32.3	35.2	49.6	41.4	39.5
2003	38.3	45.5	41.4	43.1	41.4	35.4	30.1	40.7	54.9	34.1	44.1	38.1	40.6
2004	39.1	38.6	45.5	34.9	54.4	46.3	61.8	44.3	32.8	35.2	31.9	38.5	42.0
2005	38.1	42.5	39.3	40.6	37.0	41.5	32.8	43.5	39.3	36.0	37.7	39.8	39.0
Average	**40.2**	**40.6**	**42.7**	**41.4**	**39.5**	**41.3**	**39.5**	**42.8**	**40.1**	**37.1**	**38.9**	**39.7**	**40.3**

Source: URS Holdings, Inc., with data provided by the ACP

Graph 4-9 compares the average monthly wind velocity and the monthly maximum velocities registered at the Limon Bay, Gamboa, and Balboa Stations.

Graph 4-9
Average Monthly and Maximum Wind Velocity
Stations of Limon Bay Period 2001-2005 (ELB),
Gamboa (EG), and Balboa FAA (EB) Period 1995 – 2005



Source: URS Holdings, Inc., with data provided by the ACP

Tables 4-46 and 4-47 show the records of wind direction for the Gamboa and Balboa FAA stations. Upon comparing the data obtained with the Wind Rose (Graph 4-14), it may be seen that the winds at both stations, during the entire year, always had a westerly direction with paths that ranged from south-southwest (SSO) to north-northwest (NNO).

Table 4-46

Wind Direction (degrees)

Gamboa Station

For the 1996 - 2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	349.7	4.4	344.8	333.4	348.5	297.6	304.0	302.1	278.8	144.8	285.6	346.4
1997	339.9	5.3	349.2	338.8	336.1	294.9	312.3	309.1	297.5	313.0	283.6	332.2
1998	337.2	338.7	340.9	328.9	310.0	294.3	293.1	286.5	147.1	162.1	307.5	304.8
1999	356.2	357.0	350.6	336.8	306.0	291.0	297.4	281.0	162.0	172.9	297.2	306.3
2000	357.1	8.2	358.1	337.0	322.8	303.5	301.6	298.8	50.9	289.8	302.7	314.0
2001	344.2	352.2	326.7	343.1	316.5	316.1	310.2	304.3	294.1	306.3	296.8	297.8
2002	331.4	359.1	349.0	342.3	338.3	325.2	302.3	294.8	299.7	288.5	309.4	329.7
2003	341.7	338.6	337.5	325.4	324.1	318.7	306.7	293.4	341.0	99.0	292.8	320.7
2004	1.2	352.9	1.9	340.5	331.8	298.0	305.3	296.9	129.8	276.6	295.9	332.8
2005	356.5	350.7	326.9	319.3	298.4	118.0	295.2	291.5	285.4	139.7	277.8	321.0
Average	**311.5**	**246.7**	**308.6**	**334.6**	**323.3**	**285.7**	**302.8**	**295-8**	**228.6**	**219.3**	**294.9**	**320.5**

Source: URS Holdings, Inc., with data provided by the ACP

Table 4-47

Wind Direction (degrees)

Balboa Station

For the 1996 - 2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	331.9	346.1	342.4	329.2	202.7	297	301.2	337.2	279	216.3	278.3	335.1
1997	336.9	344.2	349.7	341.8	334.2	287.6	325.3	326.6	316.5	285.4	288.3	337.5
1998	341.5	336.8	346.8	335.4	328.7	307.5	314.8	309.9	219.8	206.7	308.5	327.7
1999	357.5	354.4	351.4	338.4	315.8	300.7	320.8	299.7	193.6	194.5	316.2	327.4
2000	351.8	353.4	354.7	354.5	321.3	302.9	311.6	299	184.5	301.7	296.3	313
2001	328.6	332.9	325.6	336	295.9	296.3	298.3	302.8	267.9	267.8	303.8	319.1
2002	340.3	352.2	348.6	346.7	292.7	256.6	319.8	313.1	239.3	287.9	323.3	331.3
2003	355.1	347.9	352.6	337.4	317.4	191.4	311.8	284.1	190.5	174.2	311.6	327.9
2004	347.6	347.6	359.2	342.6	318.2	317.9	321.7	321.2	209.9	204.3	314.3	336.8
2005	351.2	352.4	336.2	335.7	300.1	190.7	289.7	291.3	293.9	186.6	313.8	329.3
Average	**344.2**	**346.7**	**346.7**	**339.7**	**302.7**	**274.8**	**311.5**	**308.4**	**239.4**	**232.5**	**305.4**	**328.5**

Source: URS Holdings, Inc., with data provided by the ACP

4.5.2.6 Solar Radiation

Solar radiation is intensified principally in the months of the dry season, which is normally the first four months of the year. As this season begins, toward the end of December, the values of solar radiation increase significantly to values above 10,000 Langleys, while during the remaining months they show values below 8,000 Langleys.

At the Limon Bay, Gamboa, and Balboa Stations, it is during the month of March that the highest values are recorded for average solar radiation of 12,578, 11,800.49, and 12,774.09 Langleys, respectively. The lowest intensity was registered in the month of November at the three Meteorological Stations: 8,287 Langleys at Limon Bay, 7,861 Langleys at Gamboa, and 8,609.03 Langleys at Balboa FAA. The monthly averages within the above mentioned parameters are shown in Tables 4-48, 4-49, and 4-50, as well as in Graph 4-10. The radiation value may also change, depending on the presence or lack of arbor vegetation and its density; the same is true concerning the presence of clouds during the year.

Table 4-48

Monthly and Annual Solar Radiation (Langleys)

Limon Bay Station

For the 2002 - 2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2002	13,494	13,796	12,348	11,483	11,238	7,787	8,464	9,005	9,633	8,861	8,391	12,334	126,834
2003	11,860	11,700	13,081	10,363	5,332	7,703	10,429	13,892	12,583	9,630	5,608	8,077	120,258
2004	13,169	12,900	12,471	10,404	11,066	10,579	10,163	9,705	12,463	12,423	8,902	12,114	136,359
2005	11,943	12,224	13,131	11,765	9,534	11,563	11,238	9,507	10,139	12,622	10,246	14,193	138,105
Avrg.	**12,617**	**12,655**	**12,758**	**11,004**	**9,293**	**9,408**	**10,074**	**10,527**	**11,205**	**10,884**	**8,287**	**11,680**	**130,389**

Source: URS Holdings, Inc., with data provided by the ACP

Table 4-49

Monthly and Annual Solar Radiation (Langleys)

Gamboa Station

For the 1996 - 2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1996	7,797	8,226	10,161	8,783	8,076	7,511	7,820	9,537	10,077	9,876	7,560	8,716	104,139
1997	11,249	9,848	12,764	11,662	9,803	10,057	10,198	10,690	9,557	9,607	8,191	10,837	124,463
1998	10,637	10,130	12,312	11,602	10,570	8,530	8,918	8,773	10,042	9,369	8,105	8,246	117,235
1999	11,754	9,775	12,023	10,944	9,118	8,210	8,415	8,691	8,636	8,848	7,537	6,534	110,485
2000	10,531	10,894	11,996	10,393	7,870	6,996	7,824	7,353	8,311	7,946	8,476	7,756	106,346

2001	9,408	10,664	12,314	10,178	9,147	8,258	7,723	8,356	8,702	9,799	6,804	8,827	110,180
2002	12,998	11,906	12,550	11,300	11,253	7,493	7,988	8,390	8,564	8,551	7,454	10,364	118,811
2003	10,624	10,089	12,325	10,349	7,356	7,151	7,151	7,455	8,220	8,061	9,619	8,000	106,398
2004	8,502	10,431	11,197	10,137	8,597	7,615	7,336	6,893	9,002	9,426	7,450	10,111	106,697
2005	9,493	9,298	10,364	10,543	7,804	7,683	6,525	6,582	6,490	8,443	7,423	9,845	100,493
Avrg.	**10,299**	**10,126**	**11,800**	**10,589**	**8,959**	**7,950**	**7,990**	**8,272**	**8,760**	**8,993**	**7,862**	**8,923**	**110,525**

Source: URS Holdings, Inc., with data provided by the ACP

Table 4-50

Monthly and Annual Solar Radiation (Langleys)

Balboa Station

For the 1996 - 2005 Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1996	10,362	10,773	14,824	12,118	10,880	8,132	8,821	9,481	8,998	9,248	7,927	7,676	119,240
1997	9,900	8,614	11,460	10,321	9,213	8,515	8,901	9,031	7,933	7,189	8,345	11,444	110,866
1998	11,580	9,811	11,603	10,521	10,615	9,095	9,305	9,184	11,370	9,588	9,132	7,954	119,758
1999	10,350	10,231	12,375	11,693	10,059	8,561	9,181	9,700	9,796	9,866	8,645	7,472	117,930
2000	10,144	11,552	12,004	11,716	9,819	8,938	9,319	9,480	10,350	9,689	9,445	8,681	121,137
2001	12,431	12,712	13,570	12,135	10,766	9,944	10,055	10,188	8,875	9,568	8,523	8,495	127,263
2002	10,688	12,523	13,703	11,543	11,654	7,774	9,482	9,914	10,001	8,670	7,726	9,255	122,934
2003	9,672	10,095	11,421	9,961	8,661	7,579	14,295	13,904	13,437	10,639	9,112	9,482	128,257
2004	12,099	13,467	13,484	11,893	9,764	9,596	10,095	9,412	12,073	11,436	9,939	9,969	133,229
2005	11,700	12,362	13,297	12,832	11,606	10,736	10,692	9,945	9,533	9,175	7,296	7,825	126,998
Avrg.	**10,893**	**11,214**	**12,774**	**11,473**	**10,304**	**8,887**	**10,015**	**10,024**	**10,237**	**9,507**	**8,609**	**8,825**	**122,761**

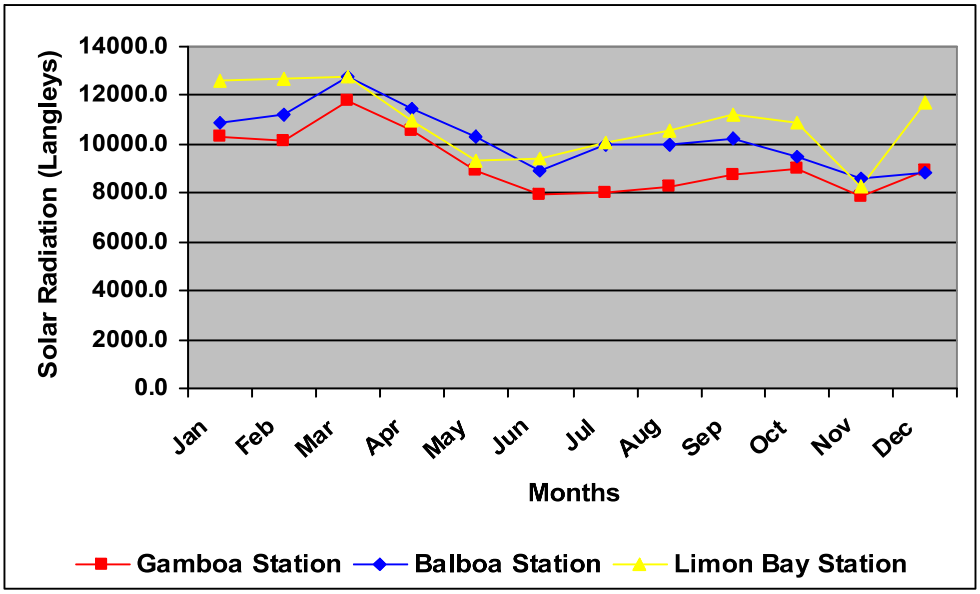
Source: URS Holdings, Inc., with data provided by the ACP

Graph 4-10

Average Monthly Radiation

Limon Bay, Gamboa, and Balboa FAA Stations

For the 1996 - 2005 Period



Source: URS Holdings, Inc., with data provided by the ACP

4.5.2.7 Potential Evapotranspiration

According to the data obtained from the ACP Meteorological Section for the 5- year (2001-2005) and the 10-year recording period (1996-2005), evapotranspiration was estimated at the Meteorological Stations located at both ends of the Canal: the Limon Bay Station in the Atlantic and the Balboa Station in the Pacific. Evapotranspiration calculated for both stations is higher in the months of January through April (dry season) and it begins to decline from May to November (rainy season); in December it begins to increase until the cycle is completed in January.

Average evapotranspiration a the Limon Bay station is 1022.8 mm, with a median monthly maximum of 131.8 mm in the month of February, and a median monthly minimum of 65.5 mm in the month of June (Table 4-51). The Balboa FAA Station recorded an average evapotranspiration of 1013.0 mm with a maximum of 994 in the month of March and a minimum of 58.18 mm in the month of November (Table 4-51).

Table 4-51

Monthly Measurements of Potential Evapotranspiration (mm)

Limon Bay (2001-2005) and Balboa (1996-2005) Stations

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Limon Bay Hydrometeorological Station													
2001	---	---	---	47.8	28.3	30.6	23.6	41.1	82.3	99	83.7	74.4	511.3
2002	133	146	129.5	117.7	101.4	61.4	68.3	52.8	58.2	52.8	66.8	124	1112.3
2003	131	121.5	133.5	100.8	48.7	57.8	81.6	110.6	97.1	71.9	41.4	74.9	1071.3
2004	134.5	132.4	135.4	99.6	92.1	85.2	79	75.5	96.6	97.2	72.4	119.1	1219.5
2005	120.3	127.3	118.8	108.1	74.7	92.7	94.1	73.6	69.9	98.9	82.5	138.1	1199.6
Average	**129.7**	**131.8**	**129.3**	**94.8**	**69.04**	**65.54**	**69.32**	**70.72**	**80.82**	**83.96**	**69.36**	**106.1**	**1022.8**
Balboa Hydrometeorological Station													
1996	80.4	95.2	132.9	106.5	81.2	57.1	63.9	68.8	63.9	68.8	61.1	60.7	941
1997	84.1	79.4	116.4	103.8	83.8	65.4	72.8	74.3	58.3	52.9	62.1	104.3	958.1
1998	114.8	96.5	127.5	104.8	90.2	69.3	71.5	69.4	89.6	76.6	65.9	56.7	1033.3
1999	85.5	95.7	118.6	104.2	78.6	62.7	70.7	72.9	75.4	75.6	65.1	57.3	963
2000	87.7	106.9	116.6	113	81	68.7	73	66.6	71	66.4	64.2	63.6	979.2
2001	103.9	117.1	123.3	113.8	85.9	72.7	73.5	75.9	61.1	66.3	59.1	58.2	1011.1
2002	87.1	112.9	127.4	98.5	101.7	61.4	68.5	71.5	69.8	59.4	53.1	71.3	983.1
2003	87.6	94.4	102.4	90	61.8	48.1	107.7	103.3	97.1	70.4	58.2	65.6	987.3
2004	97.3	120.1	131.4	106.4	76.5	71.4	72.3	67	90.8	83.4	73.1	89	1079.1
2005	103.6	119.2	119.9	112.1	88.5	82.6	78.6	70	64.8	61.9	47.4	55.6	1004.8
Average	**93.2**	**103.74**	**121.64**	**105.31**	**82.92**	**65.94**	**75.25**	**73.97**	**74.18**	**68.17**	**60.93**	**68.23**	**994**

Source: URS Holdings, Inc., with data provided by the ACP

4.6 Hydrology

This section summarizes the most important hydrological characteristics of the Area of Study. Among the features that were considered, the following were developed:

- Water Quality
- Availability of Surface Water Resources
- Present Usage of Surface Water Resources
- Underground Waters
- Currents, Tides, and Waves in the Atlantic and Pacific Sectors

Each stated feature is described for their relevance to the six (6) defined zones within the Specific Study Area, with extends from the Atlantic Coast to the Pacific Coast. Concerning the feature being studied (water quality, availability of water resources, etc.), when the available information allows, there is an explicit reference to the Specific Study Area and/or the Area of Direct Impact.

The description of the following features are derived from a review of the literature on studies and consulting done on behalf of the Panama Canal Authority (ACP), for which detailed information is included in the Bibliography chapter.

4.6.1 General Aspects

One of the water elements of greatest importance within the Area of General Study is the Panama Canal Watershed, which extends over a surface of 336,650 hectares. According to the Environmental Viability Report *(Informe de Viabilidad Ambiental)* (ACP, 2006i), the water potential of the Watershed has made it possible to supply the consumption need of the inhabitants of Colon, Panama and its surrounding areas, and the operations of the Canal (ship transits), in addition to the generation of hydroelectric power. The average annual water utilized in the period of 1994 – 2003 for the uses stated above was more than 4.2 billion cubic meters (ACP 2006*l*). The Watershed is made up of three lakes (Gatun, Miraflors and Alhajuela) and six and six secondary watersheds (the rivers Chagres, Gatun, Boqueron, Pequeni, Trinidad, and Ciri) Graph 4-15).

The system of artificial lakes Alhajuela and Gatun regulates runoff and allows the operation of the Canal locks, distributing the flow of the Watershed between the Caribbean and the Pacific spillways, in response to the water requirements to perform lockages, generate hydroelectric power, and to supply water to the city of Panama and other populated areas.

The results of monitoring conducted by ACP from 2001 to 2006 show that there is very good water quality in the basin of the Chagres River and the Gatun and Alhajuela reservoirs. It may be concluded from these studies that the water quality of Gatun Lake falls within the category of good to excellent; nevertheless, it must be noted that the Chagres River has a finite capacity for assimilation (ACP, 20006h – Report on the Water Quality in the Panama Canal Watershed). This study concludes that the water quality at the monitoring stations in the Panama Canal Watershed ranges mainly between good and excellent, qualifying it as adequate for various uses, healthy, and having the capacity of self-filtration.

4.6.2 Quality of Superficial Waters

Most of the quantitative data presented below are to be found in the Report on the Panama Canal Watershed Water Quality 2003 – 2005, Volumes I and II, Year 2006. These data are compared with guideline values [(Annex 2-Hydrologic Values Guide of the United States Environmental Protection Agency (EPA-USA, 1986)].

4.6.2.1 Atlantic Coast

The Caribbean marine zone is a secondary coastal zone with a muddy/sandy bed (35-70% slime and clay) that reaches a depth of 40 meters. The coast is sandy and has small bays and coves, and in many areas there is a band of coralline reefs and marine grass, although the biodiversity is reduced as a result of the human impact associated with the development of the region.

Limon Bay and the coastal flatlands in the Atlantic sector are land areas of the old Chagres River estuary. Limon Bay (~75 km^2) is a saltwater area, generally shallow, that has been refurbished to provide a good anchorage for boat; this has been accomplished by dredging activities in specific areas. The Bay is protected from the action of the waves by a breakwater, which practically cuts off any connection with the sea, except for the approach channel and a channel to the east that connects with the ports of Manzanillo and Evergreen. There are some sites in the Bay, more toward the west, that are the remains of the environment prior to the construction of the Canal, in which may be found corals, marine grasses, and other benthic flora and fauna, although not in good state. Generally the floor of the Bay is very muddy and has organic features (>80% slime and clay, ~10% organic material).

The Bay is used mainly for Canal operations, where the maintenance and operation has historically been associated with the deposit of dredged materials. According to the sampling activities undertaken in this area, the results (D`Croz *et al*, 1994) show that the water quality is acceptable and that the concentration of heavy metals in the sediments is within normal range for coastal areas. (ACP-ESM/PAC 2003).

Water quality studies conducted in the Cristobal area, within the development framework of the Environmental Impact Study for the Expansion of Cristobal Port (Ingemar, Panama, 2005), conclude that this area has good water quality that is suitable for sustaining life. This study indicated that the opening of the breakwater to gain access to Manzanillo port resulted in the improvement of the water quality; similarly, another indicator of good water quality is the presence of coral colonies *Siderastrea siderea* in the rock fill of Cristobal Pier. The results obtained and the monitoring conducted as a part of said study are shown in Table 4-52 and the location of monitoring sites is shown in Graph 4-16.

Table 4-52

Water Quality at Cristobal Area Sites

Parameter	Unit	PPCC Dock	Telfer PPCC
PH		*	8.2
Transparency	%	*	98.8
Color		*	Colorless
Mineral Oils	mg/L	*	0
Phenol Indices	mg/L	*	0
Suspended Particles	mg/L	*	837.9
Temperature	ºC	28.5	29.0
Conductivity	mmhos/cm	48620.0	49420.0
Dissolved Oxygen	mg/L	6.2	5.7
Salinity	%	30	31
Cadmium	mg/L	<0.02	<0.02
Oils and Grease	mg/L	<0.1	<0.1
Total Hydrocarbons	mg/L	<0.001	<0.001

Parameter	Unit	PPCC Dock	Telfer PPCC
Total Coliforms	CFU/100ml	0	0
Fecal Coliforms	CFU/100ml	0	0
Streptococcus sp	CFU/100ml	*	(-)
Salmonella sp	CFU/100ml	*	(-)

* Was not analyzed.

Source: Environmental Impact Study of the Cristobal Port Expansion (Ingemar Panama, 2005)

Studies conducted by ACP (PB Consult, 2006) on sediment characteristics show that in the Atlantic sector, these are composed in large part by slime (44.1%) and sand (30.2%), and in lesser proportion by clay (24.1%) and gravel (1.6%). As a part of this study 13 samples of sediment were taken in the Atlantic sector.

With regard to the quality of the sediments, studies conducted by PB Consult show an average content of 2.7 %organic carbon uniformly distributed throughout the sampling area, except at sites A.6.1 and A.6.2 (Graph 4-16) where this content is at approximately 5%, which may have been caused by the influence of a precise source.

Concerning trace metals, the presence of Barium, Lead, Mercury, Nickel, Vanadium, and Zinc has been identified. The largest concentrations of these metals were found to be below the level of a safety hazard, with the exception of mercury, whose levels of concentration are above the referenced safety levels of <0.15 mg/kg, specifically for the sample taken from site A.3.1[8] (Graph 4-16).

All the samples (Graph 4-16) show the presence of pesticides, albeit in very low levels overall. An analysis of the pesticides did not show in any of the samples the presence organic phosphate[9] compounds. Of those pesticides for which there is a reference of safety levels in sediment[10], this zone, there were none that showed up exceeding those levels.

8 Aside from the metals mentioned, the study included in every instance an analysis for Arsenic, Cadmium, Chrome, and Copper.

9 Including the samples taken from Gatun Lake, Culebra Cut, and Pacific.

10 Panama Canal Commission, Analysis of bottom sediments-1974. Channel Deepening Project and Feasibility Study for the Culebra Cut Widening-1987, Office of Executive Planning.

The results of concentrates of Biphenyl Polychlorides (PCB) in sediments show concentrations very much below those of safety levels, upon comparison with other coastal sediments of Central America, as well as correlating them to established safety levels (50,000 ng kg-1[10]). Further, the various concentrations of PCB show a relation with regard to the size of the sediment particles, which denotes they originated from some unknown source a long time ago.

Concerning Polyaromatic Hydrocarbons, their composition is very similar throughout all the zones and sampling sites. They present conditions that are typical of partially burnt hydrocarbons with petroleum contamination. The main concentrations in the Atlantic sector were observed in the Cristobal anchorage and the Colon Pier (Graph 4-16).

Tributyl Tin (TBT) a compound used to prevent incrustations on vessels and is known to have negative effects on mollusks in concentrations of 1ug/kg (O'Connor 1996), was detected[11] in samples taken near the docks and anchorages. In the specific case of the Atlantic sector, levels of 130 ug/kg were detected in sample A.2.2 (Graph 4-16). It is quite probable that the activities outside the anchorage, such as anchoring, towing by towboats, or repairs or painting caused the production of paint chips with TBT content as a result of the physical abrasion or paint spills. The low distribution of TBT in the canal suggest that this accumulation came about mainly directly in or adjacent to the anchorages, which is consistent with the absence of persistent currents that would disseminate the sediments to other areas[12].

Concerning the current of waters that flow naturally into the Atlantic Coast sector, there have been approximately 20 rivers and brooks identified, among them the rivers Williams, Piña, La Providencia, Indio, Iglesias, Grande, Coco Solo, Chagres, Caño Sucio, Buena Vista, Arenal, Aguas Claras, and the brooks Paulina and Morito, among others. Of these, Chagres River is by far the one with the greatest water potential and constitutes the main contributing source of water to Gatun Lake and, through the Gatun reservoir and locks, to the Caribbean sea in the Atlantic Coast sector. The Chagres River has its source in the San Blas mountain range and its drainage

[11] The detection limit for the method used was 20 ug/kg.

[12] ACP, 2007. Reply to comments by ANAM on the Category II Environmental Impact Study: Widening and Deepening of the Pacific Entrance.

in Zone 1, from Gatun Lake to the Atlantic. A more detailed description of the features of this river is presented as part of the Specific Study Area of Zone 3.

4.6.2.2 Gatun Locks

The aquatic environment of the zone provides the backdrop for the locks operations and vessels transit. In this zone, Gatun locks, the presence of just one body of water has been identified—Agua Clara River, which has a drainage area of 584 hectares extending to the bridge near the townsite Jose Dominador Bazan (formerly Davis townsite) and an estimated hydraulic capacity of 0.18 m3/s[13].

In the aforementioned study, (Louis Berger, 2004), there were on-site measurements taken of the physical parameters of water quality at 9 sites of this river (pH, conductivity, temperature, turbidity, dissolved oxygen (OD) and total dissolved solids) and samples of water were taken at two sites to be analyzed in the laboratory within microbiological and chemical parameters (fecal coliforms, DBO5, DQO, nitrates, nitrites, phosphates, and total dissolved solids). The water quality assay was conducted based on its usage (fishing, recreation, or aesthetics), using, for this purpose, the surface waters evaluation criteria of the Chilean Standards for water quality. Based on the findings, the stated report indicates that in general terms the water is of good quality. No important sources of contamination was found, with the exception of two sites with dissolved oxygen of < 4 mg/l (a value level at which there could be limitations on aerobic life) where the water had been dammed or flowed very slowly, and a site close to the townsite Jose Dominador Bazan where the highest turbidity was registered (28.7 NTU) and a value of 3600 NMP for fecal coliforms, both values may be responding to the discharges of effluents in that populated area.

4.6.2.3 Gatun Lake

In forming the Gatun Lake, an area of 45,000 hectares was flooded. The lake receives from its principal effluents, an average of 2.744 billion cubic meters of water annually. Further

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[13] The Louis Berger Group, Inc., 2004. Final Environmental Evaluation Report of options for the construction of new locks and the deepening of the Pacific and Atlantic entrances to the Panama Canal.

contributions to this system come from other rivers and brooks of secondary, minor watersheds that have not been gauged, which have been estimated at 40% of the surface collection of the system, for a total annual net contribution of 1.031 billion cubic meters. (ACP, Panama Canal Master Plan, 2006*l*).

The waters are used for various purposes, including: source of raw water for human supply (Canal operating areas, returned areas, Arraijan, Colon, and part of the cities of Panama and La Chorrera, through the Miraflores, Monte Esperanza, and Laguna Alta purifying plants), vessels transit, generations electric power, agroindustrial activities, recreation, tourism, and fishing.

In terms of water quality, studies undertaken indicate that the water quality—while its physical/chemical composition may vary, depending on the site where assayed—is generally good. Gatun Lake, as an artificial lake, has an excellent water quality (URS, 2005c). The same is indicated in the Modeling Study of the Quality of the Lakes *(Estudio de la Modelación de la Calidad de los Lagos)*, in which it is indicated that the parameters for water quality in Gatun Lake are below the maximum allowable level for human supply as established by entities such as the World Health Organization (WHO) (Chloride=250 mg/l and total dissolved solids+1000 mg/l) (United States Army Corps of Engineers, 2000).

The level of suspended solids in the lake varies depending on the location of the sampling site and the season of the year. The western side of the lake is always clearer due to its greater depth (which does not allow the suspension of fine sediments rising up from the floor of the lake by the action of the waves). To the east, the waters are more turbid due to its lesser depth and the constant transit of vessel and occasional dredging activities. During the dry season, there is a much more marked contrast between the deep lake waters and the navigational channel. The range of values for suspended solids in the lake is of 1-78 mg/l (ACP, Panama Canal Master Plan, 2006*l*).

The oxygen saturation levels in the lake are kept high (80-90%) during the dry season, and they decrease to around 60% saturation in the rainy season. The concentration of nutrients dissolved in lake waters is low. For instance, nitrates show averages of less than 0.2 mg/l. Nitrogen, in inverse agreement with the annual pattern of oxygen levels, follows a cycle of higher concentrations during the rainy season because of the amount of organic matter transported by the rivers.

Although the levels of nutrients are low, generally speaking, Gatun Lake has an excessive growth of aquatic plants such as hydrilla and water lilies in certain areas. This is owed to the presence of a concentration of nutrients higher than the average for precise sources, as well as the shape of its banks (margins) which serve as protection against the actions of waves and currents.

According to measurements taken by ACP (2004), chloride levels in the Gatun Lake are below 20 mg/l; likewise, conductivity levels range between 44.6 y 144.3 uS/cm.

The Panama Canal Authority Water Quality Unit established 11 stations to collect water samples and parameters register at two depths in the Gatun Lake (0.5 meters from the surface and 1 meter from the floor), implementing a regular monthly monitoring program from 2003 to 2005 (ACP 2006). The names of the collection stations are: Humedad, Raíces, Escobal, Batería 35, Monte Lirio, Barro Colorado, Laguna Alta, Gamboa, Toma de Agua de Paraíso, Arenosa, and La Represa. Graph 4-17 shows the location of the water quality sampling sites established by ACP from 2003 to 2005. Data collected at these stations from 2003 to 2005 are shown in Table 4-53.

During the sampling period (2003-2005), the average temperature ranged between 27.9 and 29.9°C on the surface and between 27.2 and 29.0°C on the floor. The thermal variation in the column of water was not significant (as shown by statistical testing); the average difference between surface and floor was 1°C. With regard to the dissolved oxygen, in general, all stations at the lake showed concentrations that were adequate for aquatic life; that is, above the reference guide value of 5 mg/l. The average values on the surface were found to be between 5.19 mg/l and 7.84 mg/l, whereas the average values for the floor were from 1.56 mg/l up to 6.92 mg/l.

The concentrations of dissolved oxygen on the floor seem to point to the presence of important amounts of decomposing organic matter. The amount of aquatic weed at the site also seem to point to important contributions of nutrients that allow their growth and the eutrophication of the waters, posing potential threats to the system of potable water supply for neighboring population.

Table 4-53

Chemical and Microbiological Parameters Registered

For the Gatun Lake (2003- 2005)

Temperature °C		Dissolved Oxygen mg/l		Nitrates mg/l		Phosphates mg/l		*Escherichia coli* NMP/100 ml		Water Quality Index
Surf.	Floor	Surf.	Floor	Surf.	Floor	Surf.	Floor	Surf.	Floor	53.71% 91-100 (E)
27.9-29.9	27.2-29.0	5.19-7.84	1.56 - 6.92	0.001 - 0.188	0.001 - 0.197	0.003 - 0.015	0.002 - 0.020	5 – 163	5 – 152	45.71% 71-90 (B) 0.57% 51-70 (R)

Note: Surf. = Surface; (E) = Excellent; (B) = Good; (R) = Regular.

Source: ACP Water Quality Report for the Panama Canal Watershed, 2003-2005 Volume II.

Regarding nitrates, the average concentration recorded on the surface for the entire 2003-2005 period varied between 0.001 mg/l y 0.188 mg/l. On the floor, the values ranged between 0.001 mg/l up to 0.197 mg/l. The highest value was 0.415 mg/l on the surface and 0.379 mg/l on the floor. It is worth noting that at the Toma de Agua de Paraíso 10% of the values (nitrates) were above the recommended guideline value (0.3 mg/l), used as a maximum guide to avoid eutrophication. Likewise, the Gamboa Station (2005) also recorded an atypical value that exceeded that of the recommended guideline. The Gamboa station receives waters from the middle course of the Chagres River, which are rich in nutrients, resulting in an increase in this area in the concentration of this item (organic matter), with the decrease of dissolved oxygen.

For its part, the average concentration of phosphates registered for the entire period varied between 0.003 mg/l and 0.015 mg/l on the surface, while the average values ranged from 0.002 mg/l up to 0.020 mg/l on the floor. The maximum value was 0.090 mg/l on the surface and 0.087 mg/l on the floor. The median value for phosphates was reported below the recommended guideline as allowable maximum to prevent eutrophication (0.025 mg/l) and below the detection limits of the method.

Concerning the presence of *Escherichia coli*, the average concentration recorded at all sampling stations reports values between 5 NMP/100 ml and 163 NMP/100 ml on the surface; and the average values reported for the floor ranged between 5 NMP/100 ml and 152 NMP/100 ml. The maximum value on the surface was 1014 NMP/100 ml and on the floor was 836 NMP/100 ml. The minimum value was 3 NMP/100 ml on the surface and the floor.

There was similarity at nine of the sampling stations for the median values of E. Coli, with values quite below (10 NMP/100ml) the recommended guideline values for direct contact recreational use (200 NMP/100 ml), secondary contact recreational use (1000 NMP/100ml), and water supply prior to treatment (2000 NMP/100ml). At the other two sampling stations, the median also recorded below the recommended guideline values, but in higher concentration than at the previously cited stations (50-60 NMP/100ml). Approximately 20% of the data, at the Gamboa and Paraiso Stations, were found to be above the recommended guideline value for direct contact recreational use.

The Water Quality Index (WQI) was determined at each of the sampling stations, based on the methodology developed by the United States National Sanitation Foundation (NSF). Said index includes parameters such as: fecal coliforms (in NMP/100 ml), pH, biochemical demand for oxygen in a 5-day period (DBO5 en mg/l), nitrates (NO3 en mg/l), phosphates (PO4 en mg/l), temperature change (in °C), turbidity (in NTU), total dissolved solids (in mg/l), dissolved oxygen (OD in % saturation). A value between 0 and 100 is obtained from a formula, determining water quality and use. Table 4-54 shows the NSF parameters for qualifying Water Quality Index and Proposed Use.

Table 4-54

NSF Parameters for Water Quality Index and Proposed Use

Source Condition (WQI)	USE
Excellent (91 – 100)	• Household Use
Good (71 – 90)	• Recreational • Flora and fauna preservation and reproduction • Artisan, sport, and industrial fishing
Average (51 – 70)	• Agricultural • Fishery
Poor (26 – 50)	• Industrial • Esthetic • Utilization of drag material
Very Poor (0 – 20)	• Transport of residual and assimilation waters

Source: United States National Sanitation Foundation (NSF)

As a result of applying the Water Quality Index (WQI), it was found that 53.71% of all water samples taken to evaluate this parameter was categorized as excellent; 45.71% was considered good; and only 0.57% was found to be average. According to the values of the calculated index, the waters in the Gatun Lake are suitable for the following uses: public supply, recreational, support of aquatic life.

Sediment studies carried out by PB Consult (2006) show that the composition of sediments in Gatun Lake present conditions quite similar to those of the sediments in the Atlantic sector, as they are composed by 41.9% slime, 29.7% sand, 27.4% clay, and 0.9% gravel. A total of 20 samples were taken in this zone to be able to characterize their properties.

The average organic carbon content in the sediments is 2.0%, and this points to a very poor relation of the size of the particles, which suggest that this may be owing to the existence of non-diffused carbon sources.

Concerning trace metals, high concentrations of Barium (199-353 mg/kg) were found in all the sedimentary samples, possibly because of the natural characteristics of the zone. There was a similar occurrence with Cadmium (1.28 mg/kg) with values above the safety limits of <0.6 mg/kg for the sample identified as G.12.1. Lead (32-34 mg/kg) was found at levels slightly above the safety limits of 31 mg/kg in samples G.6.1. and G.19.1.

As in the Atlantic sector, in Gatun Lake there were no pesticides—of those for which there is a reference to the safety limits in sediments—to exceed said limits.

The highest concentrations of Polyaromatic Hydrocarbons in the Gatun Lake sector were observed at the Gatun anchorage; nevertheless, the values were found to be below the safety levels.

Tributyl Tin was detected in sample G.0.1. in concentrations of 200 ug/kg.

Gatun Lake receives contributions from some 39 bodies of water between brooks and rivers. To mention a few among them, there are the brooks, Ancha, El Congal, Harina, Juan Gallegos, Leona, La Puerca, La Tagua, Larga, Las Pavas, Las 3 Hermanas, and López, among others; and the rivers Agua Clara, Agua salud, Agua Sucia, La Seda, Culo Seco, Los Hules, Gatún, Canito, Cirí, Baila Mono, Frijoles, Frijolito, Frijolita, Palenque, Pelón, Trinidad, Caño Quebrado, etc. (Graph 4-20). Following are the chemical and microbiological characteristics of some of the principal rivers within this zone. This information comes from the samples and analyses undertaken by the Panama Canal Authority Water Quality Unit from 2003 to 2005 (ACP 2006), with the purpose of monitoring the water quality in these rivers. Table 4-51 summarizes the main results obtained for each of these rivers.

Chagres River

Chagres River originates in the mountains where the San Blas range begins, at 609 msnm, then it continues its course in an east-southeasterly direction throughout its entire body of 50.8 kms, to its flow into Gatun Lake. This watershed is fed by other minor tributaries that merge along the left bank of the river (rivers, Las Cascadas or Indio Este, Piedras; and brook, Las Palmas).

The lowest temperature registered in this body of water was 24.0°C, and the highest was 27.9°C, for a median temperature of 25.1°C. Concentrations of dissolved oxygen showed a minimum value of 5.79 mg/l and a maximum value of 9.20 mg/l, for a median value of 8.4 mg/l. It is worth noting that all values registered above 5.0 mg/l, which is the minimum value guideline of adequate conditions that will allow life for most aquatic species.

Concerning nitrates in Chagres River, the lowest registered value was 0.000 mg/l and the highest was 0.277 mg/l, for a median of 0.084 mg/l. This value is quite below the value guideline of (0.3 mg/l), used as a maximum to prevent eutrophication processes. The registered values of phosphates during the sampling period varied from 0.000 mg/l to 0.038 mg/l. The average value was 0.013 mg/l. The aforementioned values were quite below the guideline value (0.05 mg/l) established as a maximum to prevent eutrophication processes in rivers whose waters flow directly into lakes or reservoirs.

The median value of the *Escherichia coli* content was 74 NMP/100 ml, which is very much below the guideline value of 200 NMP/100 ml, established as a maximum value for contact recreational use.

The values of Water Quality Index (WQI) calculated for the Chagres River up to its inflow into the Gatun Lake, for the period studied in this analysis (2003-2005) show that 31% of the WQI values may be classified as of excellent quality and 69% of the remaining values fall within the classification of good quality. Therefore, its uses may be geared toward household use, recreation, wildlife, fishing, etc.

Gatun River

Gatun River has its origins in Cerro Bruja, which is a part of the Sierra Llorona, at 650 msnm. Its course runs in a northeast to southwest direction for a distance of 45.3 kms. Its estuary is located in the northeastern section of the watershed and covers an area of 131 km^2, which represents 5.7% of the Gatun Lake water system.

The parameters analyzed include temperature, which registered a minimum of 24.3°C and a maximum of 26.7°C, for a median of 25.4°C. The concentrations of dissolved oxygen ranged from a minimum of 5.59 mg/l to a maximum de 9.49 mg/l, generating a median of 8.0 mg/l. All values were found to be above 5.0 mg/l, which is the minimum value guideline that will support aquatic life. On the other hand, the minimum value for nitrates was o.000mg/l and the maximum was 0.201 mg/l, for a median of 0.041 mg/l, which is very much below the maximum value guideline (0.3 mg/l) set to avoid eutrophication. Phosphates show low values of 0.000 mg/l and high values of 0.057 mg/l, for a median concentration of 0.030 mg/l. These concentrations were below the value guideline of 0.05 mg/l, established to prevent eutrophication processes in rivers whose waters flow into lakes or reservoirs.

The results of microbiological analysis of the water (*Escherichia coli*), show minimum concentrations of 5.0 NMP/100 ml and maximum concentrations of 5,855 NMP/100 ml. The median concentration was above the value guideline of 200 NMP/100 ml, established as the maximum for direct contact recreational use.

Upon application of the Water Quality Index, it was determined that the water quality in Gatun River may be placed in three categories: Excellent (6%), Good (91%), and Average (3%). These results allow the overall classification of the water quality in this river as good, inasmuch as 97% of the values were within the categories of good and excellent.

Caño Quebrado River

The secondary watershed of the river Caño Quebrado is located northwest of La Chorrera district. The river has its origins southeast of the community called El Amargo (in the Iturralde Borough), and runs for a total length of 19.7 kms. Its estuary covers an area of 74.4 km^2 and its main contributor is a stream called Riecito. They both converge at approximately 1 kilometer north of the Cerro La Silla community (CICH, 2003). The estuary of this river is important because it flows into an extension of the southwestern region of the Gatun Lake that serves as the water intake for the Laguna Alta Filtration Plant.

The lowest value registered for temperature was 25.1°C and the highest was 27.2°C, for a median de 26.1°C. The concentrations of dissolved oxygen ranged from 5.78 mg/l to 9.03 mg/l and the median was 7.60 mg/l. All values were above the value guideline (5.0 mg/l) used as a minimum for sustaining life of aquatic species. Nitrates ranged from 0.053 mg/l to 0.260 mg/l and the median was 0.128 mg/l, quite below the 0.3 mg/l value guideline used as a maximum reference to avoid eutrophication . Phosphates varied from the lowest value of 0.010 mg/l to the highest, which was 0.030 mg/l. La median for phosphates was 0.010 mg/l, quite below the value guideline (0.05 mg/l). Concentrations of *Escherichia coli* ranged from 132 NMP/100 ml to 1,644 NMP/100 ml, with a registered median of 300 NMP/100 ml. Most of the values were above the value guideline of 200 NMP/100 ml.

Upon applying the Water Quality Index, it was shown that 6% of the samples were of excellent quality and the remaining 94% fell in the category of good.

Trinidad River

Trinidad River has its origins on the western skirts of the hill Los Monos (893 msnm), inside the Altos de Campana National Park. In the upper part of this river, an important tributary is the river Cacao whose waters empties on the right bank, 16 kms downstream from its origin. Trinidad River has a length of 51.9 kilometers and runs in a south to north direction, and along its course, there is parallel drainage that extends into its estuary. The estuary covers an area of 198.2 km^2, which represents 8.6% of the surface of the Gatun Lake waters.

The results of chemical and microbiological analyses of samples taken from this river show that the lowest value for temperature was 24.4°C, the highest was 27.4°C and the median was 26.2°C. The range of concentrations of dissolved oxygen were from 5.67 mg/l to 8.69 mg/l, with a median of 8.00 mg/l. This values are above the value guideline (5.0 mg/l) that allows life under adequate conditions for the majority of aquatic species. The values for Nitrates varied between 0.000 mg/l to the highest value, which was 0.334 mg/l, for a median of 0.034 mg/l. Phosphates showed a low value of 0.000 mg/l and a high that registered at 0.038 mg/l. The median value for phosphates was 0.020 mg/l, registering below the value guideline (0.05 mg/l). Concentrations values of *Escherichia coli* ranged from 20 NMP/100 ml to 18,514 NMP/100 ml and the median value was 408 NMP/100 ml, a value that exceeds the established value guideline of 200 NMP/100 ml.

In keeping with the criteria of the Water Quality Index, the values obtained place the water quality of this river in the category of good.

Ciri Grande River

Ciri Grande River has its origins on the continental divide at 921 msnm, in the extreme south of the Watershed from where it runs for 51.5 kilometers in a northerly direction covering a drainage area of 208.3 km^2, which represents 9.0% of the Gatun Lake waters. It is fed by two main tributaries, which are the rivers Ciri and Ciricito, in addition to 15 smaller tributaries.

The lowest value registered for temperature was 24.1°C , the highest was 27.0°C, and the median was 25.7°C. Concentrations of dissolved oxygen registered values of 5.50 mg/l and 8.65 mg/l, for a median of 7.6 mg/l. These values allow life for the majority of aquatic species. Nitrates varied from 0.011 mg/l to 0.286 mg/l, for a median value of 0.064 mg/l; these values are far below the value guideline (0.3 mg/l) which prevents processes of eutrophication. Phosphate values ranged from 0.001 mg/l to 0.025 mg/l for a median value of 0.008 mg/l. Values for *Escherichia coli* range from 111 NMP/100 ml to 6,910 NMP/100 ml, and the median value was 408 NMP/100 ml, exceeding the value guideline of 200 NMP/100 ml.

All values calculated for the Water Quality Index in Ciri Grande River place it within the classification of Good.

Table 4-55

Maximum, Minimum and Median Values of Parameters Evaluated and their Comparison to Values Guidelines for Gatun Lake Tributaries – Zone 3

Value Guidelines	Temperature (°C)			Dissolved Oxygen (mg/l)			Nitrates (mg/l)			Phosphates (mg/l)			*Escherichia Coli* (NMP/100 ml)		
	Max V.	Min V.	Median	Max V.	Min V.	Median	Max V.	Min V.	Median	Max V.	Min V.	Median	Max V.	Min V.	Median
	NA			5.0			0.3			0.05			200		
Gatun River	25.7	25.4	25.4	9.49	5.59	8.00	0.201	0.000	0.041	0.057	0.000	0.030	5,855	5	>200
Boqueron River	27.9	23.8	25.5	9.85	5.90	8.50	0.260	0.003	0.091	0.042	0.002	0.021	15,648	5	<200
Pequeni River	28.4	23.7	25.7	9.60	6.30	8.50	0.274	0.000	0.072	0.060	0.003	0.022	4,130	10	126
Chagres River	27.9	24.0	25.1	9.20	5.79	8.40	0.277	0.000	0.084	0.038	0.000	0.013	5,731	10	74
Caño Quebrado River	27.2	25.1	26.1	9.03	5.78	7.60	0.260	0.053	0.128	0.030	0.010	0.010	1,644	132	300
Trinidad River	27.4	24.4	26.2	8.69	5.67	8.00	0.334	0.000	0.034	0.038	0.000	0.020	18,514	20	408
Cirí Grande River	27.0	24.1	25.7	8.65	5.50	7.60	0.286	0.011	0.064	0.025	0.001	0.008	6,910	111	408

Max V. = Maximum Value

Min V. = Minimum Value

Source: Report on Water Quality in the Panama Canal Watershed 2003-2005. Volumes I and II, Year 2006.

On the other hand, the Panama Canal Authority found that the dissolved oxygen in all the sampled rivers presented acceptable values for aquatic. The *Escherichia coli* parameters exceeded the value guideline of 200 NMP/100 ml for direct contact recreational use, in most of the analyzed simples. This condition was evidenced at certain particular sampling sites; consequently, this condition might be more related to the presence of wildlife and cattle than to that of human settlements. Regarding the Water Quality Index (WQI) of the totality of the bodies of water monitored, 8% may be classified as Excellent, and the remaining 92% may be classified as of Good quality. These results show that the water quality in the main rivers of the Watershed is adequate for water supply, recreational use (direct and/or indirect contact) and support of aquatic life.

4.6.2.4 Culebra Cut

In the Culebra Cut Zone, the presence of approximately 20 coursing bodies of water, between rivers and brooks, has been pinpointed. Among the brooks are Aguas Azules, De Oro, Del

Gaso; and among the rivers are Cabuya, Cabaya, Cuevas, Grande (northern inlet), Mandinga, Mariposa, Obispo, Sardinilla, Camacho, among others. (Graph 4-18).

Concerning the water quality of these rivers and brooks, The Louis Berger Group (2004) describes the features of Grande River. The delta of this river is located near the Pedro Miguel locks and it empties its waters into the Miraflores Lake. This is a Class 3 river, with a drainage area of 1,112 hectares and a length of 4.6 kilometers. It is approximately 3.00 meters wide and 0.35 meters deep and flows at an average speed of .89 m/sec with a volume of flow of approximately 0.93 m^3/sec.

In the water quality analysis done on the river Grande (TLBG 2004), the physical parameters of this river were found to be pH of 7.2, temperature of 27.0°C, and turbidity of 5.6 NTU. At the time of the samplings, it had a concentration of dissolved oxygen of 6.1 mg/L and no salinity was recorded; the concentration of total solids was 89.2 mg/L. The chemical and microbiological parameters in this river presents a biochemical demand for oxygen in 5 days (DBO_5) of 6.0 mg/L, the chemical demand for oxygen (DQO) reached values of 13.8 mg/L. Only traces of nitrites were found and no nitrates and phosphates were detected. Fecal coliforms registered values of around 800 NMP. In general terms, the results showed good water quality, inasmuch as no important contamination sources were found.

The water quality of the rivers Mandinga, Obispo, and Camacho was analyzed as part of the Evaluation of Alternative Deposit Sites of Excavated and Dredge Material in the Pacific (Moffatt & Nichol, et al, 2004). The results obtained for these courses of water showed higher values as far a total solids were concerned, compared to the results previously showed for the river Grande, and in the case of Obispo, the values for dissolved oxygen were lower. The water quality analysis showed the following results:

- Mandinga River: pH 6.3, conductivity 604 uS/cm, temperature 31.6 ºC, turbidity 5.1 NTU, dissolved oxygen 8.4 mg/l, and total dissolved solids 258 mg/l.
- Obispo River (Obispo Inlet 3): pH 7.0, conductivity 314 uS/cm, temperature 24.0 ºC, turbidity 3.5 NTU, dissolved oxygen 4.5 mg/l, and total dissolved solids 154 mg/l.

- Camacho River: pH 7.6, conductivity 244 uS/cm, temperature 27.4 ºC, turbidity 4.6 NTU, dissolved oxygen 6.2 mg/l, and total dissolved solids 11.4 mg/l.

Concerning the sediments found in this zone, they are primarily composed of slime (61.8%) and clay (31.1%), with sand in a smaller proportion (7%). The average content of organic carbon in the sediments is at around 2.2%. For the analysis of sediments, a total of 2 samples were taken from this zone (PB Consult, 2006).

The content of trace metals for the Culebra Cut area was very similar to the conditions found in the Gatun Lake, with findings of high concentrations of Barium in all collected samples, possibly owing to the natural features of the area.

Concentrations of pesticides—for which there is a safety level reference for sediments—did not exceed these limits; nevertheless, the report cautions concerning Chlorotoluron (Urea type), found in samples CC1.21 y CC2.1 in concentrations of 5.99 and 5.97 ug/kg, respectively. Despite no reference, it is pointed out as a high level.

4.6.2.5 Pacific Locks

The Pedro Miguel and Miraflores Locks are separated by the Miraflores artificial Lake (2.8 km^2), formed by the construction of a reservoir that spans the valley of the river Grande (South Inlet). This lake receives a large volume of waters from Gatun Lake by way of the Pedro Miguel Locks, and a contribution to a lesser degree from the rivers in its watershed. As an example, while the outflows from the Gatun Lake are estimated at 5,000m^3/s, the contributions from rivers Cocoli and Grande (South Inlet) are 16 and 1,000 lower, respectively[14]. The lake level (16.5 m PLD) is regulated by a spillway that discharges its flow of water in a course on the north side of the Miraflores Locks; this discharge comes from Gatun Lake (approx. 5,000 m^3/s) (Moffat & Nichol 2005) and the flow contributed by the Cocoli River (approx. 300 m^3/s), which is the affluent of Miraflores Lake (The Louis Berger Group 2004, PB Consult 2006).

[14] Data provided by the Panama Canal Authority

The water environment of the area serves as the backdrop for the locks operations and vessel transit; it has a fair to high level of currents/energy that maintains the waters in a state of high turbidity. The waters also have a medium level of contamination because of drainage from populated areas in this region around the Canal[15].

Miraflores Lakes salinity studies conducted by the Panama Canal Authority (2004) show variables levels between 0. and 2 ppt; conductivity range from 153 to 3672 uS/cm.

The hydrographic network in this zone is conformed by over 10 rivers and brooks. Among them are brooks Conga and Victoria; and rivers Caimitillo, Cocoli, Pedro Miguel, Perico, Sierpe, Velasquez, Grande (South Inlet), among others (Graph 4-19).

Since 2003 the Panama Canal Authority has been monitoring sites that are representative of the conditions of Gatun Lake in the Culebra Cut area, and in 2006 it conducted samplings to determine the quality of rivers and Cocoli (Table 4-56). The results that were obtained from these monitoring showed that the concentrations of dissolved oxygen in the Gatun Lake stations (Culebra Cut) and, Grande River (South Inlet) are to be found in the majority of the results within acceptable values for sustaining aquatic life, ranging from 5.00 to 7.94 mg/l and from 3.52 to 8.71 mg/l, respectively; in the case of Cocoli River, the results obtained ranged from 3.04 to 4.37 mg/l. The pH values obtained at all sampling stations were within acceptable levels around 7.0. The values for total dissolved solids ranged from 60 to 838 mg/l in Gatun Lake (Culebra Cut), from 251 to 480 mg/l in Grande River (South Inlet), and from 152 to 675 mg/l in Cocoli River. Concentrations of nitrates for Gatun Lake (Culebra Cut) ranged from 0.005 to 0.377 mg/l, Grande River (South Inlet) from 0.011 to 0.050 mg/l, and for Cocoli River they ranged from 0.008 to 0.665 mg/l. Nitrites in Gatun Lake (Culebra Cut) ranged from 0.027 y 0.001 mg/l. Both rivers were found to have, for the most part, levels below 0.002 mg/l. Alkalinity in Gatun Lake (Culebra Cut) was 59 to 37 mg/l, whereas the levels for the rivers Cocoli and Grande (South Inlet) the levels were quite above the values recommended for sustaining aquatic life, ranging between 64 and 245 mg/l.

15 The Louis Berger Group, Inc. 2004. Final Environmental Report – Deepening, Pacific Sector, cited in ACP, 2007, Preliminary Environmental Evaluation.

Table 4-56

Results of Water Quality in Grande and Cocoli Rivers

Station	Coordinates	Collection Date	Time	CL	AA	Temp. ºC	Turb NTU	OD mg/l	PH Unid	Cond uS/cm	STD mg/l	NO3 mg/l	NO2 mg/l	Alkal mg/l
Grande River South Inlet Outflow to Miraflores Lake	652532, 996330	Dec 22, 05	9:50	1	3	25.3	1.8	4.95	7.17	460.0	359	0.019	<0.002	139
		Feb 9, 06	9:40	1	3	24.7	3	3.52	7.04	504.1	480	0.014	<0.002	181
		Mar 29, 06	9:49	2	2	25.8	s/d	4.50	7.21	709.0	417	0.011	<0.002	74
Grande River South Inlet Upstream	651689, 996535	Dec 22, 05	10:25	1	3	25.3	3.4	5.11	7.65	540.0	251	0.064	<0.002	171
		Feb 9, 06	10:09	1	2	26.3	6	8.71	7.46	594.1	427	0.050	<0.002	245
		Mar 29, 06	s/d	s/d	s/d	s/d	s/d	s/d	s/d	s/d	s/d	s/d	s/d	s/d
Cocoli River Upstream	s/d	Dec 22, 05	12:25	1	3	26.2	6.9	4.37	7.67	196.0	152	0.478	0.002	87
		Feb 9, 06	11:15	1	3	26.9	2.5	3.80	7.33	201.8	181	0.362	0.004	89
		Mar 29, 06	11:38	2	4	27.1	s/d	3.57	7.22	238.0	153	0.665	0.016	157
Cocoli River Outflow to Miraflores Lake	s/d	Dec 22, 05	12:45	1	4	28.2	21.9	3.04	7.30	237.0	167	0.095	0.003	64
		Feb 9, 06	11:50	1	3	28.9	3.5	4.02	7.16	522.1	380	0.008	<0.002	76
		Mar 29, 06	11:19	2	2	28.5	s/d	4.29	7.17	1020	675	0.028	<0.002	196
Gatun Lake	s/d	2003 - 2005[16]	---	---	---	30.1 27.2	133.8 6.0	7.94 5.0	8.42 7.06	194.0 93.7	838 60	0.377 0.005	0.027 0.001	59 37

Source: Category II Environmental Impact Study: Earth Movement and Leveling of Cartagena Hill. Prepared by PB International, Panama Canal Authority Environmental Division. 2007; Water Quality Report on the Panama Canal Watershed 2003 – 2005. ACP, 2006.

[16] Range of Maximum and Minimum Values obtained in this period.

4.6.2.6 Pacific Coast

This zone serves as a backdrop for the transit of vessels through the Canal and for the Balboa port operations. About 25 kilometers of the coastal zone are utilized as industrialized or urban port areas. Except for the southwestern corner where there are some green areas, a vast swamp with a strip of mangroves, and small areas of secondary forests, and thatch.

In the estuary area closest to the sea and in shallow waters on either side of the Canal, the combined action of currents and waves produce erosion and circulation of sediments. This area of the Canal is noted for a high level of sedimentation. The estuary receives all untreated drainage from Balboa, Ancon and other urban areas of Panama City, through rivers, canals, and pipelines. The level of organic contamination is very high (organic solids, bacteria, pathogens, etc.) There is not a good estimate of the length of stay of the contaminated matter in this zone, nor of its final destination, but it is true that the dispersion vector is connected to navigation, the seas, the prevailing currents of the area, circulation for fine sediments, and periods of dredging.

The Panama Bay, in the Pacific Coast Zone, is a secondary coastal zone with a very muddy bed (90-99% slime and clay), which reaches a depth of 20 meters at 10 to 15 kilometers from the coast. The seaboard is very sandy and has small inlets and coves. The zone between tides is composed of mud and sand, with extensive rocky areas. A chain of small islands, or volcanic origin, extends south of the Canal entrance.

The bodies of water that flow into this zone are the rivers Cardenas, Castillas, Curundu, Dejali, Farfan, Matutele, and Venado, among others (Graph 4-19). These bodies of water, because they are outside of the Canal Watershed, are not included in the monitoring network for water quality, therefore the available information on the quality of their waters is very limited (Tabla 4-57).

Table 4-57

Quality of the Surface Waters of the Farfan and Velasquez Rivers

Name of the River	pH	EC (µS/cm)	T^a (°C)	Turbidity (NTU)	DO (mg/l)	Salinity(ppt)	TDS (mg/l)
Farfan	8.0	52,600	28.0	23.5	7.3	32.3	24,206
Velasquez	7.1	356	26.0	3.2	1.5	-	167.5

Source: Evaluation of Alternatives for Deposit Sites of Excavated and Dredge Material in the (Moffatt & Nichol et al., 2004).

These results show the influence of natural and anthropogenic sources on the water quality of these rivers. The high level of salinity in the Farfan River is evidence to the great influence of the seas over these ecosystems. Very low levels of dissolved oxygen were registered in the Velasquez River, which, together with very high levels of conductivity, indicates that the quality of the water is poor.

Pacific sector sediments show very particular characteristics: they are composed largely by clay (50.4%) and slime (29.2%), along with sand (15.8%) and gravel (4.6%) in lesser proportion. There were 15 samples of sediments taken in this zone. (PB Consult, 2006).

The organic carbon content of the sediments in this sector presents the highest level with an average of 3.1%; similarly, the weak relation between the content of this parameter and the size of the particles in Gatun Lake suggest the existence of non-diffuse sources.

Trace metals showed concentrations of Copper (73 mg/kg) slightly above the safety level of <70 mg/kg, specifically in the case of sample P.4.1. Concerning registered parameters, such as Arsenic (7.0 mg/kg), Barium (48-61 mg/kg), Lead (20-27 mg/kg), and Zinc (108 mg/kg), all levels were below the safety standard (PB Consult 2006).

The Pacific Sector was the only zone in which the concentrations of pesticides were above the established safety levels. These results are reflected in Table 4-58 that follows:

Table 4-58

Elevated Concentrations of Pesticides in Sediments (ug/Kg)

Pacific Sector

	Halogenated Organ [17]		
Sample	4,4'-DDE	4,4'-DDD	4,4'-DDT
P.1.1	3.36	1.93	4.23
P.2.1	---	2.09	3.07
P.3.2	---	1.89	---
Reference Level	2	1	2

Source: URS Holdings, Inc. from PB Consult 2006.

The highest concentrations of polyaromatic hydrocarbons in the Pacific sector were observed in the Balboa area; the levels in samples P.2.1, P.3.2, and P.4.1 were close to or slightly above the reference level.

In the cited study (PB Consult, 2006) Tributyl Tin was found in low concentrations in all the samples except the one collected across from the Balboa Port.

Tributyl Tin (TBT) is a compound used in marine paints to prevent barnacles and other organisms from attaching to the hull of vessels and is known for its extremely harmful effects on mollusks[18]. Within the detection limit used in the sounding conducted (20 $\mu g\ kg^{-1}$), at the 16 sites examined, only one sample P.4.1 (790 $\mu g\ kg^{-1)}$), which was collected near the Balboa Port areas, showed concentrations of this substance. In port areas, concentrations usually exceed 5000 µg kg-1, and they may exceed 50,000 in extreme cases (outside of dry docks) in other parts of the world.

[17] Only shows the concentrations for those samples that exceeded the safety values used as reference. Sólo se muestran las concentraciones para aquellas muestras que excedieron los valores de seguridad utilizados como referencia.

[18] It is believed that a concentration of 1 ug kg-1 in sediments have an effect. O'Connor, P. T. (1996). Trends of the Chemical Concentrations in Mussels and Oysters along the U. S. Coast from 1986 to 1993. Mar. Environ. Res. 41 (2), 183-200.

In general terms, according to the samplings and analyses done by the Panama Canal Authority Water Quality Unit (ACP, 2006h), the water quality of the main rivers in the Canal watershed in the sampling areas is good. The majority of the samples taken meet all the pertinent value guidelines for each of the parameters analyzed. Only some samplings of phosphates and others of nitrates exceed the pertinent value guideline, nevertheless, they are within the acceptable limits set to prevent Eutrophication processes.

4.6.3 Flow Volumes (Maximum, Minimum, and Annual Average)

The flow volume is defined as the amount of water that passes through a cross section of a river for a specified unit of time (ACP, 2005a). In keeping with the preceding, data for maximum, minimum, and median flow volumes of certain rivers located within the Specific Study Area (Table 4-59) were obtained from the hydrometric stations the Panama Canal Authority maintains in the Watershed.

As may be seen in Table 4-59, Chagres River, located in the Atlantic Coast Zone, has the highest median annual discharge or medium flow volume of 26.6 m^3/s, whereas the lowest annual average for flow volume was registered for Caño Quebrado River located within the Gatun Lake Zone, registering a value of 1.94 m^3/s. The other rivers, Gatun, Trinidad and Ciri Grande register medium volumes of flow of 4.54 m^3/s, 5.66 m^3/s, and 7.39 m^3/s, respectively.

Table 4-59

Maximum, Minimum, and Average Values of Volume Flow for Rivers within the Specific Study Area

Rivers \ Flow Volumes	Maximum Flow Volume (m^3/s)	Minimum Flow Volume (m^3/s)	Annual Average Flow Volume (m3/s)
Chagres River (Z1)	730	7.20	26.6
Gatún River (Z3)	177	0.852	4.54
Caño Quebrado River (Z3)	46.0	0.178	1.94
Trinidad River (Z3)	156	0.861	5.66
Ciri Grande River (Z3)	131	1.32	7.39

Note: Z1 = Atlantic Coast Zone; Z3 = Gatun Lake Zone
Source: Hydrological Yearbook 2005 (ACP, 2006).

Similarly, the highest value registered was for Chagres River (730 m^3/s), followed by the rivers Gatun (177 m^3/s), Trinidad (158 m^3/s), and Cirí Grande (131 m^3/s), while the lowest flow volume was reported for Caño Quebrado River (46.0 m^3/s). Concerning the values for minimum flow volume, Chagres and Grande rivers reported values of 7.20 m^3/s and 1.32 m^3/s, respectively. The other rivers registered values of minimum flow volume of < 1.0 m^3/s.

Because of the high values of flow volume registered for the Chagres River, it has a high water potential, which has made meet the supply needs of the inhabitants of the cities of Colon, Panama, and surrounding areas, as well as the operations of the Canal (vessel transit). This two-fold demand for water has been met by the same water source for the past 90 years, for which it is viewed as one of the rivers of greatest importance for the Nation.

4.6.4 Currents, Tides, and Waves

The following sections present the main features related to currents, tides, and waves of the Specific Study Areas of the Atlantic Coast and the Pacific Coast because they constitute the only zones with a marine component.

4.6.4.1 Atlantic Coast

This is a secondary coastal zone with a muddy/sandy bed (35-70% slime and clay) that reaches a depth of approximately 40 meters at a distance of 4 kilometers from the coast. The seaboard is sandy, with small inlets and coves and in many areas there is a band of coralline reefs and marine grass, although their biodiversity is reduced owing to the impact caused by human development of the region. In the Atlantic Coast sector or Zone 1, the tidal fluctuation is small (~0.3 m) and the resulting currents are equally weak. There is an ocean current due to the circulation of the Caribbean Sea, which flows almost continually to the east the rate of ~0.25 m/s. Influenced by the tradewinds, the actions of the waves is medium strong (>2 m height 50% of the time with a modality period of 8-10 seconds).

4.6.4.2 Pacific Coast

Water circulation is dominated by tide-induced movements (semidiurnal) which have an amplitude of 5.0 meters in live tides and 2.7 meters in dead tides. This circulation produces currents that flow at maximum rates of 0.2-0.3 m/s generally in the estuary. The estuary zone closest to the sea and in shallow waters on both sides of the Canal the combined action of currents and waves produce erosion and circulation of sediments. This zone of the Canal is characterized by having a high level of sedimentation.

The currents of the zone are forced by the ocean current of the Gulf of Panama along with the tidal movement. The ocean current changes according to the annual seasons. In rainy season there is a current to the west in the northern area of the Gulf, that moves at a rate of approximately 0.2 m/s. In the dry season stronger winds from the Caribbean move the surface waters in a southwesterly direction, causing an upwelling of cold waters from the depths of the ocean. In the Bay of Panama the stronger flows are usually aligned in a north to south direction and are controlled by the effect of the tides and the effect of the ocean current provide a movement in a westerly direction. Maximum rates of the currents do not exceed 0.3 m/s. The residual flow goes to the west or southwest.

The waves in the Bay are formed by local winds and a swell that comes in from the ocean in a south-southwest to west-southwest direction (200-250º). In deep waters the normal swell has a width of 1.0 m to 1.75 m and a cycle of 10-18 seconds, but this energy is dissipated more in the Bay and toward the Canal entrance it is less vigorous (the condition that occurs every 100 years is 0.7 m width with a cycle of 17 s). Local winds can form waves of an amplitude of 1.0 m and a cycle of around 4 seconds during storms. Currents induced from the passing of a wave are very strong in shallow waters and in combination with ocean currents and tide-induced currents may erode and transport sediments from the bottom of the Bay; this is an important consideration in the analysis of the destination of dredged material deposited in the ocean.

It must be noted that the Pacific Coast is highly influenced by the Colombia Current. Said current moves in a counterclockwise manner with a predominantly NNE direction and is shown in all intensity between Cape Manglares (Colombia) and Punta del Coco (Costa Rica), playing an important role in the dynamics of sedimentation and disposition of the sandy bars parallel to the coast. During the months of December to April, the velocity might be around 150 cm/sec, while from May to June it is 50 cm/sec, depending on the intensity of the winds (Stevenson, et al. 1970). This current drags low salinity waters toward the north along the Colombian coast and allows entry of lower temperature ocean waters from the equatorial transition front.

4.6.5 Underground Waters

Available information on underground waters in the Specific Study Area is very limited, mainly because the studies conducted have been focused on surface bodies as the main resources that are utilized.

4.6.5.1 Characterization of Aquiferous Layers

For the Specific Study Area, The Louis Berger Group (2004) determined that the phreatic level of the area shows a seasonal behavior pattern, which in the dry season is depressed below five (5) meters of the surface. However, because of the soil texture, which is of high plastic clay content and because there is an argillous horizon (accumulation of clays) a hanging phreatic level is produced at less than one (1) meter of the surface. These levels rise in the rainy season to less than 50 cms of the surface, causing surface drainage problems and in some cases upwelling to the surface. Deep borings performed found that the level of permanent ground waters is much deeper, between four (4) and five (5) meters of depth (Berger, 2004).

Recent studies conducted by the Panama Canal Authority in the area where the Borinquen dikes will be built reflect the existence of ground waters at levels from 0.5 to 16.6 meters, as well as phreatic levels from 12 to 26.4 meters. Prior studies (University of Panama, 2003) describe the occurrence of Canal ground waters making reference to drilled wells of 65 meters deep. That study described aquifers located from the Pedro Miguel locks with a length of 10 kilometers at the base line toward the east as well as the west of said line, to the east of the base line (Gamboa) and to the east of the Gatun locks. These local aquifers (intergranular or fissured) of limited productivity are constituted by volcanites, marine deposits, and consolidated and non-consolidated lake deposits. The meteorized zones may function as aquitards. The chemical quality of the waters varies from good quality to healthful waters.

4.7 Air Quality

The air quality continues to be one of the lesser evaluated feature in the majority of scenes worldwide, except certain precise points such as large cities and/or sites where its deterioration is so flagrantly observable that it really cannot go by unnoticed.

Most worthwhile in terms of scientific data[19] of the air quality for the Panama Canal Widening Project are a series of analyses undertaken regularly by the Specialized Institute of Analysis of the University of Panama *[Instituto Especializado de Análisis (IEA) de la Universidad de Panamá]* from mid 1996 in the city of Panama within its Pure Air program. Other air quality studies that were reviewed for this analysis include the Exploratory Study of the Quality of Air and Noise in the Districts of Panama, San Miguelito, and Colon and its Implementing Program *("Estudio Exploratorio de la Calidad de Aire y Ruido en los Distritos de Panamá, San Miguelito y Colón, y su Programa de Capacitación")* conducted by the French firm BCEOM in the years 2001 and 2002; and monitoring conducted by the Specialized Institute of Analysis of the University of Panama for the Panama Canal Authority, as a part of this current Project.

Of further interest are the studies conducted by the firm PB Consult for the Panama Canal Authority to establish an inventory of atmospheric emissions and determine the possible effects of the works on the levels of air quality in the areas adjoining the sites where widening works will be conducted during the peak construction period[20].

19 Taking into account the periods of monitoring and the techniques utilized.

20 The simulation conducted makes an estimate of the air quality only during construction phase, for which said data are not considered in this base line analysis.

4.7.1 Monitoring Sites and Evaluation Methodology

This section presents the principal methodologies applied to the monitoring for air quality as well as for analysis of the emission sources present in the site were the Project will be developed.

4.7.1.1 Air Quality Monitoring

From the studies reviewed on air quality monitoring, it may be said that the one of greatest scientific rigor is that conducted within the framework of the Pure Air Program of the University of Panama (through their Specialized Institute of Analysis), because of the continuity of said monitoring over a span of more than ten (10) years.

Among the monitoring stations established by the Pure Air Program, there are three sites considered to be of interest for this Environmental Impact Study because of its location with respect to the areas defined in this work as the Specific Study Area and the Area of Direct Impact. These stations are those of Casco Viejo—adjacent to the Pacific entrance to the Canal; the station identified as Balboa—next to the present Balboa crafts market and next to the YMCA[21]; and the station identified as Curundu—on the campus grounds of the Harmodio Arias Madrid University, near the Balboa port area.

The measurements taken by the firm BCEOM included monitoring the concentrations of certain indicative features of air quality for two months during the summer and two months during the winder in the years 2002 and 2003 at different sites in the area of Colon. Of interest to this study, because it was within the Specific Study Area, are the results obtained for the Cristobal Port area.

The most recent of the studies conducted within the Project development zones is the monitoring, currently underway by the Specialized Institute of Analysis of the University of Panama for the Panama Canal Authority, which includes the evaluation of air quality in the

[21] This station was closed in the year 2001

Miraflores Locks area and the Gatun Locks area. This monitoring has been underway since January 2007 and will run until the month of August 2007.

To complement these studies, within the framework of the implementation of this Project, monitoring of air quality, specifically of particles, in the townsites of Paraiso, Cocoli, and Fort Davis are being conducted since April of this year to date.

The location of the sites of these monitoring activities is presented in Graphs 4-20 and 4-21.

All of the aforementioned sites were and/or are the object of environmental monitoring through passive, continuous and/or gravimetric methods. The studies evaluated environmental concentrations for Nitrogen Dioxide (NO_2); Sulfur Dioxide (SO_2); Ozone (O_3); particles smaller than 10 microns (PM_{10}) and y at a lesser frequency, levels of Carbon Monoxide (CO); while the most recent included monitoring of particles smaller than 2.5 microns ($PM_{2.5}$).

The monitoring sites and parameters evaluated in each of these studies are summarized in Table 4-60 that follows.

Table 4-60

Air Quality Monitoring Sites and Parameters Evaluated

According to Available Studies 1997 – 2007

Site	Geographic Coordinates		Study	Parameter			
	X	Y		NO_2	SO_2	O_3	PM_{10}
BALBOA	658648	989869	U. DE PANAMÁ - IEA				
CURUNDU	658648	989869	U. DE PANAMÁ - IEA				
CASCO VIEJO	661318	989978	U. DE PANAMÁ - IEA				
CRISTOBAL	620299	1033992	BCEOM - IEA - ANAM				
MIRAFLORES	593799	1044933	IEA - ACP				
GATÚN	611064	1043689	IEA - ACP				
COCOLÍ	655150	992247	URS - IEA - ACP				
PARAISO	650788	998435	URS - IEA - ACP				
JOSE DOMINADOR BAZAN (FORT DAVIS)	620091	1026370	URS - IEA - ACP				

Source: URS Holdings, Inc.

Table 4-61 summarizes the monitoring methods used in these studies.

Table 4-61

Methodology of Air Quality Monitoring and Analysis

Reference Methods	Parameter	Range
EQSA-0595-100 US EPA Fluorescent Spectroscopy	SO_2	500 ppb
ETH – Switzerland – Passive Tube Glycerin capture / ρ-Rosaniline UV		
RFNA-1194-099 US EPA Spectroscopy	NO_2	500 ppb
ETH – Switzerland– Passive Tube Palmes tube-Griess-Saltzmann method		
EQOA-0992-087 US EPA chemoluminescence	O_3	400 ppb
ETH – Switzerland – Passive Tube		
RFPS-1287-063 Andersen High Volume Sampler	PM_{10}	N/A

Source: URS Holdings, Inc.

4.7.1.2 Estimates of Current Emissions

In the report submitted by contractors Parsons Brinckerhoff (2006), the principal sources of emissions resulting from the Canal operations, expansion works, and other sources existing at the site were analyzed. To estimate emissions, the source of information used was equipment capacity, load factors, rate of use, number of equipment in operation, emission factors (mainly from the United States EPA), and data on sulfur content in marine bunker. A large part of this data was provided by ACP staff based con operating conditions and work practices carried out for the evaluated equipment and areas.

4.7.2 Results Obtained for Specific Study Area

The results obtained from the various air quality studies carried out, according to the zone in which these were carried out, are shown in Table 5-62, whereas in Table 4-63 the reference values are shown. Further, Table 4-64 show the results of emission estimates.

Table 4-62

Air Quality Results

Site	Parameter (ug/m³)[19]							
	NO_2		SO_2		O_3		PM_{10}	
	Annual Average	24 hrs	Annual Average	24 hrs	8 hrs.	24 hrs	Annual Average	24 hrs
Atlantic Coast-Zone 1								
CRISTOBAL	17.10		3.10		27.73		47.80	58.1
Gatun Locks – Zone 2								
FORT DAVIS								22.2
GATÚN*	7.6		65.7		26.0		24.7	
Pacific Locks – Zone 5								
PARAISO								23.4
MIRAFLORES*	15.6		20.6		48.7		20.9	
COCOLÍ								18.6
Pacific Coast – Zone 6								
BALBOA	31.70	40,20			38.80		49.09	41.6
CURUNDU	13.00	38,20			16.70		25.30	
CASCO VIEJO	20.70				14.00		13.50	

* = Average of months: January, February, March, April, and May 2007

Source: URS Holdings, Inc. Specialized Institute of Analysis, ACP

Table 4-63

Value Guidelines or Reference Standards

Value Guideline	NO_2		SO_2		O_3		PM10	
	Annual Average	24 hrs	Annual Average	24 hrs	Annual Average	24 hrs	Annual Average	24 hrs
PAHO-WHO[22]	80	160	80	365	157	235	50	150
PAHO-WHO[23]	40	200	20	500	100		20	50
ANAM[24,25]	100	150	80	365	157	235	50	150
EPA	100		80	365	157	235	100	

Source: URS Holdings, Inc.

22 Value Guidelines of PAHO-WHO up to October 2006.
23 New Value Guidelines of PAHO-WHO since October 2006.
24 Air Quality Draft Project
25 Value Guidelines considered in Standard 2610-ESM-109 established by the Panama Canal Authority coincide with the values considered in the ANAM's Air Quality Standard Draft.

Most of the values that appear in Table 4-62 fall within the standards of the agencies that are listed in Table 4-63, except for the cases of PM_{10} which at almost all the sites do not meet the PAHO-WHO new guidelines, as well as Sulfur Dioxide in the Gatun Locks zone that is above the PAHO-WHO new guidelines for this item.

Table 4-64 shows the results of the calculations for the emissions sources inventory.

Table 4-64

Estimate of Existing Emissions[26]

Activity	Emission Source	Parameter (Ton/day)			
		CO	**NOx**	**PM_{10}**	**SO_2**
Maritime Operations	Vessels Transit	48.6	141.0	4.1	76.3
	Dredging and Drilling	0.3	2.9	0.1	3.8
	Tugboats	1.1	10.8	0.3	14.4
	Service Vessels	1.8	2.7	0.1	NA
	Subtotal	**51.8**	**157.4**	**4.6**	**94.5**
Modernization Program	Lirio	0.09	0.26	0.02	0.03
	Hodges	0.17	0.46	0.03	0.05
	Bas Obispo	0.11	0.27	0.02	0.03
	La Pita South	0.07	0.20	0.01	0.02
	Cartagena	0.16	0.42	0.03	0.05
	Subtotal	**0.60**	**1.61**	**0.11**	**0.18**
Other Sources	Miraflores Thermoelectric Plant	NA	12.5	0.70	6.10
	Train Service	0.00002	0.00004	0.0000024	---
	Vehicular Traffic	3.7	0.50	0.10	0.02
	Subtotal	**3.7**	**13.0**	**0.80**	**6.12**
Total		**56.10**	**172.01**	**5.51**	**100.80**

Source: Parsons Brinckerhoff, 2006.

26 In some instances, the total sum of emissions was adjusted according to the result of each of the individual components.

It is observed from said calculations that for all the parameters evaluated, the main sources of emission are related to maritime operations, particularly the transit of vessels through the canal.

The results obtained, evaluated by zones are shown below[27].

4.7.2.1 Atlantic Coast

The air quality obtained in this sector for NO2, SO_2 and O_3 is within the value standards and/or reference for this parameter. In the case of PM_{10}, it was observed that the annual average data as well as the 24-hour concentration values obtained surpassed the new value guidelines defined by PAHO-WHO.

In addition to the maritime sources of emission of the area, it is worth mentioning other adjacent sources, such as the Cristobal Incineration Unit and the Mount Hope Sanitary Landfill, which often presents problems of spontaneous combustion.

4.7.2.2 Gatun Locks

In measurements conducted at the Gatun Locks, NO_2 and O_3 are observed within the referenced values; the values of SO_2 and the annual average of PM_{10} surpass the new PAHO-WHO guidelines.

On the other hand, monitoring of PM_{10} conducted in the Jose Dominador Bazan (Fort Davis) area is within the reference parameters used.

4.7.2.3 Gatun Lake

The monitoring conducted did not take into account the Gatun Lake area. Nevertheless, in general terms, the existing sources of contamination consist mainly of constant vessel transit,

[27] Emissions due to maritime operations, train service, and vehicular traffic do not correspond to any particular zone, but are distributed throughout the different Specific Study Areas.

inasmuch as a large part of the surface area of the zone consist mainly of water areas and there is no urban or industrial development of any import in that area.

4.7.2.4 Culebra Cut

There are no air quality reference data for this zone, either. Because this area is surrounded by forests and its population density is low, the actual air quality should be one of low concentrations of air pollutants. The contaminant of highest concentrations, because of the conditions of the terrain, could be Ozone, which tend to increase its production in wooded areas. The levels of particles generated as a consequence of the modernization works that are actually being undertaken may be viewed as an important contaminant[28], but very specific, because they are being generated either by the construction machinery being used or earth movements being carried out; nevertheless, it must be noted that these actions may be lessened in a large measure by the high humidity conditions of the area, especially with the approach of the rains.

4.7.2.5 Pacific Locks

The largest contributor identified in this zone up to now is canal traffic, particularly large ships using bunkers with high sulfur content; another source of emissions in the area is the Miraflores thermoelectric plant, located next to the locks.

Monitoring conducted at the locks show that NO_2, and O_3 are within referenced values. It was observed that SO_2 and PM_{10}, slightly exceed the new PAHO-WHO parameters.

Precise data for PM_{10} obtained in the communities of Cocoli and Paraíso show compliance with the reference standards and guidelines.

[28] Los sitios Lirio, Hodges, Bas Obispo y La Pita Sur se encuentran dentro de esta zona.

4.7.2.6 Pacific Coast

This is the most studied zone of all in terms of air quality, since there are continual monitoring stations within this area.

The results obtained from the monitoring show higher levels of contaminants in those stations located next to roadways with high vehicular traffic. For the most part, there is compliance with the reference standards, except for the annual average value of PM_{10} at the Balboa and Curundu stations, which exceed the guidelines established by PAHO-WHO.

The values of PM_{10} for the Balboa station—where average values were close to 50.00 $\mu g/m^3$, and the largest concentrations of NO_2 were measured—leads to conclude that the air quality is more compromised in heavily trafficked areas, as is the case of this station that receives the emissions of vehicular traffic en route to the Bridge of the Americas.

From the results presented, it is worth pointing out the temporary nature of the majority of the data, inasmuch as they are gathered from monitoring conducted at very specific times, and not reflecting a more permanent and continual study of air quality.

Concerning the new guidelines for air quality issued by PAHO-WHO, it is important to state that by defining much more stringent standard than previously were in place, to be able to comply, intermediate objectives need to be set for the gradual reduction of contaminants in the air until the new proposed levels are achieved.

4.8 Noise

The objective of this section is to establish the base line conditions with regard to noise levels in those urban and recreational zones which, due to their proximity to work zones of the Widening Projects and because of the activities to be developed there may be considered sensitive receptors.

The base line existing conditions on noise were established using secondary information generated from the Parsons Brinckerhoff study (2006) and from conducting additional monitoring by the University of Panama. The data obtained correspond to measurements at fifteen (15) points located in La Boca, Diablo, Los Rios, Clayton, Paraiso, Pedro Miguel, Summit Golf Club, Summit Botanical Garden, Gamboa, and Jose Dominador Bazan (Davis) in the Atlantic sector. At certain points of interest, such as Jose Dominador Bazan, Paraiso, Pedro Miguel, Clayton, and Gamboa, the readings included two sites for a better coverage. Of these sites, twelve (12) are located in residential areas and three (3) in recreational areas.

4.8.1 Definition of Sensitive Receptors

The selected monitoring sites provide a wide geographical coverage to be able to characterize the range of existing noise conditions in the sensitive receptors in the environment of the proposed project area. The levels of noise for the various receptors located in the proximity of the measurement sites may be different because of topographical features of the terrain or because of distance. The receptors included the most representative sites in terms of proximity to the Canal and its current operation.

The location of monitoring sites is shown in Graphs 4-20 and 4-21.

4.8.2 Methodology and Measurement Equipment

The characteristics of existing environmental acoustic conditions in the selected sites were determined by undertaking a series of noise measurements. This was conducted by the firm Parsons Brinckerhoff in September and October 2006. The University of Panama conducted complementary measurements in March 2007, at seven of the fifteen sites measured initially.

In the study conducted by Parsons Brinckerhoff, the noise readings were taken by means of a calibrated Bruel & Kjaer 2231 Model Sound Level Meter, with a CEL-250 microphone that was shielded from the wind. The calibration of the sound level meter was verified by a Bruel &

Kjaer 4230 calibrator prior to each measurement. The Sound Level Meter computed the Leq noise level for periods of 20 minutes.

The measurements taken by the University of Panama used a calibrated Quest sound meter, model Soundpro, with a type 2 microphone with wind shield protection. The calibration of the equipment was verified prior to and after each measurement with a QC-10 calibrator. As in the Parsons Brinckerhoff study, measurements were conducted for 20-minute periods.

Information regarding the distances of these points to the Canal and its present operations is presented in Table 4-65. Measurements at all sites were taken during the daytime in the morning and afternoon at 8 a.m. and 5 p.m., approximately. In addition to these periods, noise level readings were taken at nighttime between the hours of 11:59 p.m. and 3 a.m., approximately, at 6 of the 15 sites. The level of equivalent noise (Leq.) was determined during the measurement period and L10 or level of excessive noise 10% of the times during the measurement period.

Table 4-65

Distance of Measurement Points from the Project Works

Monitoring Site ID	Approximate Distance from the Project Works (Meters)		
	Approximate Distance to the proposed locks in the Pacific	Approximate Distance to the proposed locks in the Atlantic	Approximate Distance to Approach Channel
ZONE 2 – Gatun Locks			
M1	-	848	471
M2	-	1191	469
ZONE 3 – Gatun Lake			
M11	-	-	102^
M12	-	-	109^
ZONE 4 – Culebra Cut			
M13	-	-	1614^
M14	-	-	1083^

Monitoring Site ID	Approximate Distance from the Project Works (Meters)		
	Approximate Distance to the proposed locks in the Pacific	Approximate Distance to the proposed locks in the Atlantic	Approximate Distance to Approach Channel
ZONE 5 – Pacific Locks			
M5	-	-	379
M6	-	-	447
M7	-	-	615
M8	-	-	797
ZONE 6 – Pacific Coast			
M3	4977	-	520^
M4	2870	-	650
M9	2293	-	2045
M10	1851	-	1780
M15	1590	-	-

Source: Parsons Brinckerhoff, 2006.

^ Distance at this site was measured to the east back of the Canal.

4.8.3 Sites and Results of Noise Measurement

The details and results of the measurements by Parsons Brinckerhoff 2006 and the University of Panama 2007 are shown in Table 4.66. Based on the data shown in said table, it is followed by a discussion of these parameters as they pertain to the Specific Study Area of each reading.

Table 4-66

Levels of Existing Background or Environmental Noise

Monitoring Site ID	Monitoring Site Location	Land Use	Date	Time	Leq (1h) (dBA)	L10 (dBA)
ZONE 2 – Gatun Locks						
M1	Jose Dominador Bazan (Davis)	Residential	Sep 9,2006	11:50 am	44	45
M2	Jose Dominador Bazan (Davis) - # 1 Pedro Prestan Avenue	Residential	Sep 9,2006	12:32 am	53	58
ZONE 3 – Gatun Lake						
M11	Gamboa - # 308 Gaillard Ave	Residential	Oct 3,2006	4:15 pm	66**	62**
			Oct 3,2006	5:23 pm	56	55
			Oct 5,2006	10:14 am	53	54
			Oct 5,2006	11:59 pm	46^	48
M11a	Gamboa - # 308 Gaillard Ave	Residential	Mar 28,2007	4:00 p.m.	63.7	87.5[3]
M12	Gamboa - # 167 Williamson Ave	Residential	Oct 3,2006	4:52 pm	50	52
			Oct 5,2006	9:43 am	53***	56***
ZONE 4 – Culebra Cut						
M13	Summit –Gulf Club	Recreational	Oct 4,2006	1:06 pm	50	52
M14	Summit – Botanical Garden Municipal Park	Recreational Park	Oct 4,2006	1:45 pm	55	60
M14a	Summit – Botanical Garden Municipal Park	Recreational Park	Mar 27,2007	5:40 p.m.	54.9	68.4
ZONE 5 – Pacific Locks						
M5	Paraiso - # 120A Vista Hermosa	Residential	Oct 2,2006	3:10 pm	47*	50*
			Oct 5,2006	8:48 am	48*	51*
M6	Paraiso - # 359 Paraiso Rd	Residential	Oct 2,2006	5:06 pm	58*	56*
			Oct 4,2006	10:55 am	61*	62*
			Oct 5,2006	12:44 am	49^	49
M6a	Paraiso - # 359 Paraiso Rd	Residential	Mar 26,2007	3.42 p.m.	71.8[1]	58.6
M7	Pedro Miguel - # 9207-2 Railroad crossing and Omar Torrijos Ave	Residential	Oct 2,2006	3:47 pm	67	71
			Oct 4,2006	10:14 am	73 */**	71*/**
M8	Pedro Miguel - # 908 Manzanillo Pl	Residential	Oct 2,2006	4:30 pm	64	66
			Oct 4,2006	9:47 am	59	-
			Oct 5,2006	1:16 am	49^	49
ZONE 6 – Pacific Coast						
M3	La Boca - # 912-A Ernesto J. Castillero R. Street	Residential	Oct 2,2006	10:45 am	55	57
			Oct 4,2006	4:10 pm	57	60

Monitoring Site ID	Monitoring Site Location	Land Use	Date	Time	Leq (1h) (dBA)	L10 (dBA)
			Oct 5,2006	3:04 am	52^	52
M3a	La Boca - # 912-A Ernesto J. Castillero R. Street	Residential	Mar 23,2007	2:20 p.m.	56.2	67.1
M4	Diablo - # 5964 Smith Pl	Residential	Oct 2,2006	11:45 am	60	63
			Oct 4,2006	3:10 pm	62	65
			Oct 5,2006	2:27 am	53^	54
M4a	Diablo - # 5964 Smith Pl	Residential	Mar 23,2007	3:05 p.m.	63.5	81.2[4]
M9	Clayton – Sports Complex City of Knowledge – Jarman Field	Residential / Sports	Oct 3,2006	2:12 pm	52	54
			Oct 4,2006	8:38 am	53	55
M9a	Clayton – Sports Complex City of Knowledge – Jarman Field	Residential/ Sports	Mar 3,2007	4:40 p.m.	58.6[2]	72.7
M10	Clayton – # 25B Carlos Renato Lara Street	Residential	Oct 3,2006	3:02 pm	60	62
			Oct 4,2006	9:12 am	56	57
			Oct 5,2006	1:50 am	46^	47
M15	Los Rios – Crossroads Bible Church	Residential /Church	Oct 4,2006	2:32 pm	67	70
M15a	Los Rios – Crossroads Bible Church	Residential /Church	Mar 3,2007	6:30 p.m.	57.7	80.5[5]

Source: Modified from Parsons Brinckerhoff, 2006. The measurements with superscripts were taken by the University of Panama.

* Reading taken during Canal construction activities.

** Train passed by during reading (reading includes train noise).

*** At 9:54 am during reading, there was a sub aquatic explosion (drill barge Thor).

^ Night reading.

Note 1: M5 – Approximate distance from the construction area at Paraiso Hill, 883 meters.
M6 – Approximate distance from the construction area at Paraiso Hill, 361 meters.
M7 – Approximate distance from the construction area at Paraiso Hill, 1083 meters.

Note 2: No construction work was observed during the night readings.

Note 3: Each noise reading lasted 20 minutes.

[1] Constant vehicular traffic

[2] Constant vehicular traffic, car alarms, and airplane route

[3] People talking

[4] Dogs barking

[5] Vessels transiting, people talking, airplane route, birds.

As seen in Table 4-66, the results of the measurements of noise taken during the daytime hours range from Leq 44 to 73 dBA, and from Leq 46 to 53 dBA during the nighttime hours. Following are the results obtained according to each zone defined within the Specific Study Area (AEE), as compared to the provisions in effect regarding environmental noises (Executive Decree Nº306 of 2002[29]).

4.8.3.1 Atlantic Coast

This zone was not included as part of the monitoring taking place since the works to be performed in this zone will be of an aquatic nature, hence, the level of noise produced by these works will not be significant in relation to the high volume of port and commercial activity taking place in the zone and quite close to residential areas.

4.8.3.2 Gatun Locks

Parsons Brinckerhoff 2006, performed measurements in the community of Jose Dominador Bazan (Davis), taking two readings (sites M1 y M2).

For the daytime measurements performed in this zone at sites M1 and M2, results vary from Leq 44 – 53 dBA, leading to the conclusion that this zone is barely affected by levels of noise. At no time did the values obtained exceed the limits established by the provision for environmental noise during daytime hours (60 dBA).

4.8.3.3 Gatun Lake

In the Parsons Brinckerhoff 2006 consulting work, measurements were taken in the community of Gamboa, establishing two noise monitoring sites (sites M11 and M12). Readings were taken during the day—in the morning and afternoon hours—at both monitoring sites. In addition, a night reading was taken at site M11.

[29] Modified by Executive Decree Nº1 of 2004.

The University of Panama performed complementary measurements in Gamboa - #308 Gaillard Ave. (site M11a), during the daytime hours.

A train went by (background noise) while taking a daytime reading at site M11. Table 4-62 shows the background or environmental noise readings at site M11 with and without the influence of the train.

The noise reading at site M12 during the morning hours included noise originating from an underwater explosion (background noise) off drill barge Thor. This zone is affected sporadically and intermittently by blasting activities in the Canal (Culebra Cut).

Some of the sources of noise identified in the area originate from the Dredging Division in Gamboa, the cargo and passenger train, and vehicular traffic on local streets.

The results of daytime measurements varied from Leq 50 – 66 dBA, and during the night the results were Leq 46 dBA. These results show that in some cases the national standard for daytime hours, 60 dBA, was exceeded; however, in both instances in which said level was exceeded, very special situations where observed that may have caused the excess, such as the train passing and people talking.

4.8.3.4 Culebra Cut

The monitoring sites in this zone included a daytime noise reading at the Summit Golf Club (site M13) and the Summit Botanical Garden Municipal Park (site 14), located on the East side of the La Pita excavation area. The University of Panama took measurements at the Summit Botanical Garden Municipal Park (site M14a) during the daytime hours.

In Zone 4, all measurements were taken during the daytime, with results ranging from Leq 50 – 54.9 dBA. This site is relatively distant from the navigation channel; the main source of noise originates from occasional vehicles. The results reflect compliance with the daytime value established by national standards.

4.8.3.5 Pacific Locks

Two noise readings (sites M5 and M6) were taken in the community of Paraiso. At both sites, measurements were performed in the morning and afternoon hours. In addition, a night reading was taken at site M6. The University of Panama also took noise measurements in Paraiso - #359 Rod (site M6a) during the daytime.

Two noise monitoring sites were located in the Pedro Miguel area (sites M7 and M8). At both sites, daytime readings were taken in the morning and afternoon. Additionally, a night reading was taken at site M8. The community of Pedro Miguel is located east of the Canal. The railways are located to the west of Pedro Miguel.

It is important to mention that while the daytime readings were taken at sites M5 and M6, excavation works were being performed on the west side of the Canal in Paraiso Hill. Noise from constant vehicular traffic was characteristic during the daytime measurement at site M6.

At site M7, a train went by (background noise) while the monitoring of the daytime reading was performed. Table 4-54 shows the reading of background or environmental noise at site M7 with the influence of the train and without it. Some of the sources of noise identified in this area were from cars, buses, and trucks that transit Omar Torrijos Avenue, as well as from the cargo and passenger train. During the daytime reading taken at site M7, construction works were underway on the west bank of the Canal at Paraiso Hill.

In this zone, the results of the daytime measurements ranged from Leq 47 – 73 dBA, and nighttime measurements ranged from Leq 46 – 49 dBA. The zone is mostly residential; consequently, the source of noise is principally from household activities and other external sources such as the passing train and the constant vehicular traffic. There is compliance with the values of the environmental noise standards (50 dBA) for nighttime; however, the only site that complied with the daytime value limit was site M5.

4.8.3.6 Pacific Coast

In the community of La Boca (site M3), noise measurements were taken during the day (morning and afternoon hours) and night. The University of Panama took measurement in La Boca – 3912-A, Ernesto J. Castillero R. Street (site M3a), during the daytime hours.

In Altos de Diablo (Altos de Jesus), noise readings were taken (site M4) during the day and night. Some of the noise sources identified at this site originated from cars and trucks that transit Alemania Street. Likewise, the University of Panama performed measurements in Diablo - #5964 Smith Pl, (site M4a).

In the Los Rios community (site M15), a noise reading was taken during the day, close to the Crossroads Bible Church.

In the Clayton community (City of Knowledge) two noise readings were taken (sites M9 and M10). At both monitoring sites the readings were taken during the day—morning and afternoon hours. In addition, a nighttime reading was taken at site M10 (residential area). The City of Knowledge is an area of mixed land use with residential, office, and commercial zones. The University of Panama also took noise measurements in Clayton, specifically at the City of Knowledge Sports Complex – Jarman Field (site M9a).

Some of the sources of noise identified at site M3 originated from vehicular traffic on the Bridge of the Americas and in adjacent towns.

Regarding the Altos de Diablo (Altos de Jesus) community, site M4, the sources of noise identified originated from cars and trucks on Alemania Street. In the measurements taken at site M4 by the University of Panama, a source of noise characteristic to the zone was barking dogs and pedestrians.

A factor that characterized the measurement at site M9a was the airplanes flying above, as well as vehicular traffic and sounds from alarms.

In Los Rios community—close to the Crossroads Bible Church, site M15a—noise perceived during the measurements originated from diverse sources such as people talking, airplanes flying above, and birds.

In Zone 6, the measurements taken during the day ranged from Leq 52 – 67 dBA, and at night they ranged from Leq 46 – 53 dBA.

The sites with the greatest levels of noise recorded were in Diablo, with Leq 63.5 dBA, and in Los Rios, with Leq 67 dBA, both parameters being above the 63 dBA limit for daytime hours. Regarding the nighttime measurements, the only site that did not exceed the normal value of 50 dBA was Clayton, which registered Leq 46 dBA.

4.9 Odors

Odor is an organoleptic property perceived by the olfactory organ through the inhalation of certain volatile compounds. Discomfort from odors may have physical as well as mental effects. According to the World Health Organization (WHO), odors are detrimental to human health. In some instances, perceived odors may be bothersome to humans, and have a negative impact on the sense of well being, and potentially cause secondary effects such as headaches and nausea[30].

Odors are characterized by different factors: i) Intensity: which measures the strength of the perceived sensation; ii) Acceptability: which measures the grade of like or dislike of an olfactory sensation; and iii) Odor Threshold: which determines the minimum concentration of an olfactory sensation capable of originating a response[31]. Odors may be generated by various types of sources, such as natural sources, sources created by man and his activities, and those generated by industrial activities—whether stationary, mobile, etc.

As part of this Environmental Impact Study, to characterize the odors in the Specific Study Area of the Panama Canal Expansion Project, a review of the current literature on studies in the

[30] Final Scientific and Technical Study – Quality Control Standards for Bothersome Odors, URS Holdings, Inc. November, 2004.
[31] Elements of Successful Odor /Odour Laws. St. Croix Sensory Inc., 2004.

country (which is very limited) was conducted, focusing particularly on work performed by URS Holding, Inc., in 2004. Later, applying the methodology and criteria recommended in said study, selected points of the Specific Study Area were monitored in the month of March 2007.

This section initially shows a brief description of the background on the measurement and characterization of odors, and the results of the monitoring conducted in the Specific Study Area.

4.9.1 Selection of Sample Points at Specific Study Area

The sample points for the present study were selected considering the six study zones as defined in the current Environmental Impact Study, according to the following criteria:

- Communities within the six study zones of the Project for the environmental component; and
- Zones with economic activities (tourism, industrial, recreational, educational adjacent to the study zone).

It should be noted that the sites selected considered the sample points evaluated by the Panama Canal Authority in the Noise Levels Evaluation, conducted by PB Consult, 2006[32], given that although said study focused on the subject of noise, it considered the receptors closest to the sites where Canal expansion works will take place.

Finally, the communities considered for monitoring in the Gatun Lake Zone were selected using as a reference the results of the study in the river communities of Gatun Lake, performed by the Panama Canal Authority[33] social work team.

In total, 32 sample sites were selected, the locations of which are shown in Graph 4-22.

32 Parsons Brinckerhoff , 2006. Task Order #30 - Chapter 5: Noise Levels Evaluation.

33 Field Study Report. Riverside Communities to Gatun Lake, from February 14 to 18, 2005. Panama Canal Authority Community Relations and Social Investigations Team, 2005.

4.9.2 Methodology of Measurement of Sources of Offensive Odors

The field olfactometer (Nasal Ranger) was used to measure field odors, in addition to a GPS to mark the monitoring points, photographic camera, and pre-designed field sheets forms. For control purposes, two measurements were recorded at each point by two different technicians. It should be noted that all measurements were taken during the dry season.

A list of the steps followed during the sampling of bothersome odors at each of the selected sites is listed below:

- Field measurement with Nasal Ranger (olfactometer).
- Concurrent measurements by two field technicians and with a time interval of approximately 5 minutes.
- Measurements downwind and upwind.
- Recording of geographic coordinates with GPS and measurement of dilution limits (D/T) detected.
- Recording of information on the existing climatic conditions: relative humidity, wind velocity and direction, overhead clouding, etc.
- Photographic records.

4.9.2.1 Description of Measurement Equipment

The Nasal Ranger operates using a series of calibrated dilutions by mixing environmental odors with air filtered through odorless carbon filters. In olfactometry, this process is defined as Dilution to Threshold (D/T). This is a measurement of the number of dilutions required to take environmental odors to no detectable levels. This dilution factor was defined by the U.S. Public Health Service (currently EPA) in the 50's and 60's. The field olfactometer calculates this dilution rate as follows:

$$D/T = \frac{\text{Volume of Air filtered with Carbon}}{\text{Volume of Environmental Air with Odor}}$$

Literature cites dilution limits between 2, 4, 7 and 15 as reference values for odor provision. The olfactometer may measure dilution limits that range from 2 to 60, being 60 the most diluted and 2 the least diluted. In using this field measurement system, the more intense the odor, the greater number of dilutions are required to avoid detection. According to the instructions for use, to avoid interference of odor persistence in the olfactory system of the technician, the measurement is initiated with the greatest dilution in the instrument (60), so the odor is not detected and subsequently dilutions are diminished until the odor is detected. The value of the dilution recorded constitutes the threshold or dilution threshold (D/T). Nevertheless, if dilution 2 is reached with no detectable odor, it may be reported as 0 value (absence of odor).

The use of the olfactometer is common in the United States and considered the procedure to follow for odor standards in evaluating complaints from the community and compliance with said standards.

4.9.3 Results of Odor Measurement

The following is a description of the results of measuring the intensity of bothersome odors at the 32 established sampling sites. The highest intensities are also reported. Detailed results are shown in Table 4-67.

Monitoring the intensity of odors was done from March 26 – 28, 2007, by the URS Holdings, Inc., staff at 32 sites selected within the Project area.

The fieldwork was complemented by several interviews with Ministry of Health government officials to obtain a general idea of the potential sources of odors within the area of study. Among the Ministry of Health government officials interviewed in the Colon Region, were the Environmental Health and Water Quality Coordinator, Engineer Ricardo Chong; the Acting Deputy Chief of Environmental Sanitation, Mr. Alfredo Sevillano; the Technical Inspector for the Sardinilla and Salamanca Area, Mr. Ruben Castro; and Miss Indira Lindo, Technical Inspector of Environmental Sanitation Quality (communities of Escobal and Cuipo). Interviewed on the Pacific side was Dr. Max A. Pinzon, Head of the Paraiso Health Center, Ancon Borough, and Head of the Metropolitan Health Region.

Table 4-67

Results of Measurement of Bothersome Odors

Study Zone	Location	Site	Place	Coordinates X	Coordinates Y	Intensity (D/T)	Description of Odors	Sampling Date	Time	Conditions	Wind Direction	Humidity
Gatun Locks	Davis	1	Residential/Agency use	619789	1025942	0		Mar 27,2007	9:45 a.m.	Sunny	In favor	61
	Davis	2	Residential	618556	1025576	0		Mar 27,2007	9:50 a.m.	Sunny	In favor	61
Gatun Lake	Escobal	3	Adelaida Herrera School	613945	1011381	0		Mar 27,2007	11:30 a.m.	Sunny	In favor	58
	Escobal	4	Park	613942	1011379	0		Mar 27,2007	11:35 a.m.	Sunny	In favor	58
	Escobal	5	Residential	613356	1010419	0		Mar 27,2007	11:45 a.m.	Sunny	In favor	58
	Escobal	6	Residential	613713	1012438	0		Mar 27,2007	11:55 a.m.	Sunny	In favor	58
	Gamboa	7	Park	642568	1007986	0		Mar 26,2007	11:00 a.m.	Very cloudy	In favor	76
Culebra Cut	Summit	8	Recreational/Municipal Park	648375	1002094	4	Moist soil	Mar 26,2007	11:35 a.m.	Very cloudy	In favor	79
	Summit	9	Recreational/Municipal Park	648449	1002020	0		Mar 26,2007	11:45 a.m.	Very cloudy	In favor	79
	Summit	10	Recreational/Golf Course	649734	1000657	15	Moist soil	Mar 26,2007	11:55 a.m.	Partly cloudy	In favor	74
	Summit	11	Recreational/Golf Course	649805	1000544	15	Moist soil	Mar 26,2007	12:05 p.m.	Partly cloudy	In favor	74
Pacific Locks	Paraiso	12	Residential	651288	997904	4	Vehicle fumes	Mar 26,2007	12:45 p.m.	Partly cloudy	In favor	59
	Paraiso	13	Residential	651361	997878	0		Mar 26,2007	1:00 p.m.	Partly cloudy	In favor	59
	Paraiso	14	Roadside/play area	651548	998001	15	Vehicle fumes	Mar 26,2007	1:05 p.m.	Partly cloudy	In favor	59
	Paraiso	15	Roadside/play area	651472	998073	30	Vehicle fumes	Mar 26,2007	1:10 p.m.	Partly cloudy	In favor	59
	Pedro Miguel	16	Residential	652522	997147	60	Garbage	Mar 26,2007	1:15 p.m.	Partly cloudy	In favor	58
	Pedro Miguel	17	Residential	652500	997164	4	Garbage	Mar 26,2007	1:20 p.m.	Partly cloudy	In favor	58
	Pedro Miguel	18	Residential	652671	997086	2	Moist soil	Mar 26,2007	1:25 p.m.	Partly cloudy	In favor	58
	Pedro Miguel	19	Residential	652836	997004	0		Mar 26,2007	1:30 p.m.	Partly cloudy	In favor	58
Pacific Coast	Los Rios	20	Church	656712	993336	0		Mar 26,2007	1:55 p.m.	Partly cloudy	In favor	68
	Los Rios	21	Residential	656779	993302	0		Mar 26,2007	2:10 p.m.	Partly cloudy	In favor	68
	Los Rios	22	Residential	656939	993157	0		Mar 26,2007	2:15 p.m.	Partly cloudy	In favor	68
	Diablo	23	Dock	656854	991334	30	Shellfish	Mar 26,2007	3:12 p.m.	Sunny	In favor	60

Study Zone	Location	Site	Place	Coordinates		Intensity (D/T)	Description of Odors	Sampling Date	Time	Conditions	Wind Direction	Humidity
				X	Y							
	Diablo	24	Residential/Agency use	657323	991174	0		Mar 26,2007	3:20 p.m.	Sunny	In favor	60
	Diablo	25	Residential	657425	991240	0		Mar 26,2007	3:30 p.m.	Sunny	Against	60
	Diablo	26	Residential	657811	991428	60	Shellfish	Mar 26,2007	3:40 p.m.	Sunny	Against	60
	La Boca	27	Residential/Industrial	657852	989247	0		Mar 27,2007	2:40 p.m.	Sunny	In favor	54
	La Boca	28	Residential	658173	989148	0		Mar 27,2007	2:50 p.m.	Sunny	In favor	54
	La Boca	29	Residential/Educational	658261	989108	0		Mar 27,2007	3:00 p.m.	Sunny	In favor	54
	Rodman	30	Residential/El Tucan	654907	991225	0		Mar 27,2007	3:12 p.m.	Sunny	In favor	38
	Cocoli	31	Residential	654791	992027	0		Mar 27,2007	3:16 p.m.	Sunny	In favor	38
	Rodman	32	Roadside/Agency use/port area	655047	990086	0		Mar 27,2007	3:20 p.m.	Sunny	In favor	38

Source: URS Holdings, Inc.

4.9.3.1 Atlantic Coast

On the Atlantic Coast, the odors are specifically related to the economic activities taking place in the different communities and essentially to the management of wastewaters and trash (garbage). According to all the interviews conducted with the government officials of the Ministry of Health, the main problems regarding the emission of odors are related to hog and poultry farming activities, indoor cattle feeding operations, raw sewage discharge, dumpsite management, and septic tanks.

4.9.3.2 Gatun Locks

In the Gatun Locks sector, two sites were evaluated as receiving sources of bothersome odors located in the residential and agency use area of Jose Dominador Bazan (former Fort Davis). Both sites are specifically zoned for residential use and one combines agency use.

The results of the measurement records of odors revealed zero intensity for both sites measured. The sampling was performed during the morning hours, on a sunny day, with a relative humidity of 61%.

According to the interviews conducted in the community of Jose Dominador Bazan (Davis), the main problems lie in the management of the septic tanks.

4.9.3.3 Gatun Lake

In the Gatun Lake Zone, five sites where evaluated as receiving sources of bothersome odors. Of these, four where located in the Escobal Borough, community of Escobal, and one in the town of Gamboa. The areas under study are characterized by being mostly residential areas and there is the Adelaida Herrera School in the community of Escobal.

In the Escobal area, the results of the measurement records revealed zero intensity for all measured sites. The monitoring was performed during morning hours, on a sunny day, with a relative humidity of 58%.

According to the health authorities of the Escobal area, the main generating sources of odors are related to the discharge of sewage, waste management and, in some nearby communities, the presence of a characteristic cattle odor.

In the Gamboa sector, the results also revealed zero intensity. The measurements were performed close to noon on a very cloudy day with 76% humidity.

4.9.3.4 Culebra Cut

In the Culebra Cut sector, four sites where evaluated as receiving sources of bothersome odors. These were located in the Summit area close to the Municipal Park and the Summit Golf Club. The areas under study are characterized as being specifically for recreational use.

The results of the samplings revealed intensity values from 4 to 15. The description of the odors perceived at these sites corresponds to that of moist soil. Climatic conditions during monitoring where partly sunny, with 74% humidity.

4.9.3.5 Pacific Locks

In the Pacific Locks sector, nine sites were evaluated as receiving sources of bothersome odors. Eight of these were located in the Ancon Borough, mostly in the communities of Paraiso and Pedro Miguel, and a site in the Cocoli area. The sites monitored were located in residential areas, for the most part, close to parks and athletic fields, as well as around some residences near the Pedro Miguel Locks. In the Cocoli area, the monitoring points were characterized by being close to the canal operations area.

The intensity values of the odors reported for the sites located in the Ancon Borough range from 4 to 30. The description of the perceived odors at these sites correspond to moist soil and vehicle fumes, which coincides with field observations, inasmuch as when monitoring was performed there was a constant flow of vehicles on the Omar Torrijos Avenue which may have had an effect on the monitoring results.

Values obtained as a result of monitoring odors in the Pedro Miguel area, were from 0 to 60. The odors where described as those from vehicle fumes, moist soil, and garbage.

On the other hand, the results from the monitoring in the Cocoli area reflected a value of zero.

In the Pedro Miguel community, the main odor emission problems have been due to stagnated waters and the accumulation of garbage. In the Paraiso community, the odors were from sewage waters, product of collapsed drainages, which are reported three or four times a year.

4.9.3.6 Pacific Coast

On the Pacific Coast, twelve sites were evaluated as receiving sources of bothersome odors. Their location: Three in Los Rios community, four in the Diablo community, three in La Boca community and two in the Rodman area (Graph 4-23). The areas under study are residential areas for the most part; in certain cases, they are combined with industrial use, as in the La Boca sector and the ports in the areas of Diablo and Rodman.

The monitoring was conducted in the afternoon hours, the characteristics of the day were partly cloudy to sunny in most areas, and the relative humidity ranged from 68 to 38%, depending on the area monitored. The results of the sampling revealed zero value for most sites, only two points showed intensity of 30 and 60, corresponding to the ports area and the residential areas in the Diablo community.

The characteristics of the odors perceived were those of shellfish. It must be noted that during the monitoring conducted in the Diablo residential area, which registered an odor intensity value of 60, the direction of the wind was against the source of emission. Hence, it is to be expected that having a downwind, the intensity of odors will be sustained.

The Medical Director of the Paraiso Health Center mentioned as potential generating sources of odors the Curundu River that cuts across communities such as Curundu Heights, Albrook, and Diablo where the waters are highly contaminated and generate foul odors.

In the Diablo community, in addition to the odors emanating from the waters of the above-mentioned river, there are also complaints from the dwellers of garbage odors, specifically shellfish, reported as originating from a shrimp business located at the site and from which odors disseminate throughout the community according to the direction of the wind.

In the Los Rios community, complaints have been lodged because of the accumulation of garbage and sewage waters in some areas. In the Balboa and La Boca areas, there are reports of gasoline odors that result from the bunkering activity underway in the area.

4.10 Natural Threats

This section presents a summary of the situation regarding the natural threats in the General Study Area and Specific Study Area of the Project. Included among the natural hazards analyzed are seismicity, forest fires, floods, and the erosion and slides of high magnitude.

4.10.1 Seismicity

The Area of General Study of the Project is located in a convergence zone of structurally complex terrestrial plates. According to the specialists at the University of Panama Institute of Geosciences, this makes it an area of seismic risk. Despite its low seismicity; there is a history of events felt in towns close to the city of Panama. The seismicity in the Area of General Study is very diffuse and certain associations with existing faults (Cowan, 2001) have been identified. The seismicity detected in this region appears to be associated with the North-South convergence between the Panama block and the Caribbean plate, and the East-West convergence, between the Panama block and the North block of the Andes.

In the Central region of Panama, seismicity is associated with the earth's crust faults around the Canal and the Caribbean plate, which enter underneath the subduction of the Panama Microplate in the Distorted Belt of the North of Panama. Certain authors have proposed there is a tectonic boundary line that cuts the Isthmus of Panama in half, running in a NNW-SSE direction, which has been dubbed the Canal Discontinuity or Gatun Fracture Zone. It is believed that the traces of the distortion associated with this discontinuity continue to the sea in the Distorted Belt of the North of Panama. However, there is no geological or geophysical evidence to prove this condition (Schweig *et al.* 1999, Cowan 2001).

It is believed that the faults in this region are normal continuing faults with some of them, such as the Gatun Fault, presenting a directional component and considered the most important in the area. This is an active fault, but produces a very low level of micro-seismicity, considering that the greatest event that could originate from this fault is a M6.8, with a cyclical period of 10,000 to 20,000 years.

There are nine (9) faults in the Gulf of Panama that extend in a westerly direction, laying parallel to Las Perlas Archipelago, which appear to be active since the bottom of the sea curves towards the Southeast of the Archipelago (Cowan 2001). The only strong events that have originated in this region, that were felt in the city of Panama with VI or greater intensity in the Modified Mercalis Scale, took place in 1621 and 1971. These events appear to have originated in the area of Las Perlas fault (Víquez and Camacho 1993); nevertheless, other authors locate the event at the Distorted Belt of the North of Panama (Mendoza and Nishenko 1989) or at the Azuero Peninsula (Nischenko 1991).

The General Study Area region presents many faults, but not all have the potential to cause earthquakes; in other words, not all faults in this region are active faults. According to the study, "Earthquakes on the Isthmus of Panama" (Camacho, 2006), in the region known as Central Panama, which includes the location of the Panama Canal, seismicity is very low and, historically, it originated only one destructive event which took place on May 2, 1621. Said event resulted in damage to the city of Panama, reaching an intensity of VII on the Modified Mercalis scale (Víquez and Camacho, 1993), and its aftershocks where felt almost daily from May to August. Table 4-68 shows a summary of the main historic seismic events that took place in the General Study Area.

Table 4-68

Main Seismic Events Occurred in the General Study Area

Date	Details
November 21, 1541	Felt in the city of Panama
May 2, 1621	Epicenter in the Pacific Coast. Intensity > 7.0
May 7, 1822	Originated by convergence of the Distorted Belt of the North of Panama, Bocas. Magnitude of 7.5. Liquefaction and tsunami along the Caribbean Coast.
October 13, 1873	More severely felt in Aspinwall-Colon
September 7, 1882	Originated by convergence of the Distorted Belt of the North of Panama, San Blas. Magnitude 7.7 – 8. Liquefaction and tsunami along the Caribbean Coast and damage to the city of Panama.
February 5, 1883	Originated in the Azuero Fault – Zone under marine surface. Magnitude7.0. Minor damage in the city of Panama.
September 30,1909	Originated in Balboa Heights-Panama and Nombre de Dios-Colon
May 27, 1914	Originated by convergence of the Distorted Belt of the North of Panama, San Blas. Magnitude 6.5 – 7.2. Terminal cities Panama and Colon.
March 7, 1930	Originated by convergence of the Distorted Belt of the North of Panama, San Blas. Cities of Panama and Colon. Magnitude 6.0 – 6.5.
November 21, 1935	Originated by convergence of the Distorted Belt of the North of Panama, San Blas.

Date	Details
	Magnitude 6.5. Felt strongly in the Canal Zone.
May 2, 1943	Originated in the South Fault of Panama. Magnitude > 7.0. Strongly felt in the city of Panama.
January 4 /6, 1951	Originated in the South Fault of Panama. Magnitude 6.7, > 7.0. Preliminary and principal earthquake. Moderate damage in the city of Panama.
July 26, 1962	Originated in the South Fault of Panama. Magnitude 6.7 - 7.0. Felt strongly in the Canal Zone, with no report of damage.
January 19, 1971	Originated by convergence of the Distorted Belt of the North of Panama, Panama. Magnitude 5.5 – 6.5. Strong tremor in the city of Panama, moderate damage.
July 12, 1974	Collision Area Colombia – Panama East. Magnitude 7.3. Strong tremor and noticeable damage.
July 11, 1976	Collision Area Colombia – Panama East . Magnitude 6.8, 7.0. Two events in 4 hours. Felt strongly in the city of Panama, with no report of damage.
February 26, 2000	Originated by convergence of the Distorted Belt of the North of Panama, San Blas. Magnitude 6.1. Felt strongly in the city of Panama, minor damages.
March 16, 2002	Epicenter Bayano watershed. Intensity Mw = 5.0
August 13, 2003	Originated by convergence of the Distorted Belt of the North of Panama.

Source: URS Holdings, Inc. from The Louis Berger Group Inc., 2004

4.10.2 Forest Fires

Another hazard, not always natural, faced in the General Study Area is the occurrence of forest fires. It must be noted that in most cases, these fires, for the most part, are generated in areas covered by stumps and grasslands, which is the predominant vegetation in the Specific Study Area.

According to reports from ANAM (2002), the Program for Prevention and Control of Forest Fires identified a large number of events related to fires in the Specific Study Area for the period 1996 – 1999. These fires occurred mainly in the year 1998 and towards the Atlantic Sector. However, the recurrence or frequency of fires in the area for several years in a row is low. So, during the period from 1996 – 1999, there was a high recurrence of fires toward the west of the Pacific Coast sector and very low to the east of the Pacific Locks and Corte Culebra areas, and likewise very low toward the west of the Gatun Lake area.

In recent years, there has been considerable recurrence of fires close to the Ciri Grande and Trinidad Rivers, both within the General Study Area, and the incidence of fires in the Chagres river basin should also be noted. Areas considered as potential risk or more prone to fires within the Specific Study Area are the Chagres National Park, the Soberania National Park, Camino de Cruces National Park, and Pedro Miguel.

The Panama Canal Authority has not reported occurrences of fire in the Area of Direct Impact on surfaces with vegetation. Clearly, since the area is constantly monitored as a result of Canal operations activities, the risk of fires is very low and manageable.

4.10.3 Floods

The concept of floods, as stated here, refers to those events that take place in areas adjacent to the natural stream of the riverbed as a result of overflowing.

The magnitudes and effects of floods depend on the characteristics of the swellings resulting from intense rainfall and other related events, such as sliding inclines, the formation and breakage of natural dams and obstructions to the flow as a result of civil works.

On the other hand, in the alluvial beds, the transportation of sediments plays an important role in the variations that have taken place throughout time by the main channel and in its capacity to transport the swellings.

The processes of deposit and undercutting are activated according to the magnitude of the water velocity; hence, deposit phenomenons are predominant in periods of low and medium water leverls because velocities are relatively low and the capacity to transport sediments is reduced. When there are swellings, the velocity of flow is increased and, consequently, there is greater erosion and degradation of the banks.

Based on this definition and in view of the available information for the preparation of this investigation, areas prone to floods and their concomitant effects on the natural and human environment were not detected in any of the six (6) areas under analysis in the Specific Study Area, with the exception of the controlled spills performed by the Panama Canal Authority in its management of waters for Panama Canal operations.

The research does not document incidents in the area of study of floods with adverse or disastrous effects, mostly because the Area of Direct Impact comprises mainly locations of Panama Canal operations.

The floodable areas are classified according to the causes originating the floods. These causes are:

- Standing waters from intense rainfall on flat areas;
- Standing waters from deficiencies in surface drainage;
- Overflow of natural bodies of water;
- Overflow of swamps;
- Landslides from volcanic eruptions, earthquakes, slides, and formation of natural dams;
- Obstructions to the flow due to construction of civil works: bridges, spurs, and channeling works, housing on the river banks, and creation of dams for exploitation of alluvial material; and
- Sedimentation.

Based on this classification, no floodable zones have been identified in the area of study since most of the area is dedicated to Panama Canal operations, where flood management and control is practiced.

4.10.4 Erosion and Landslides

The loss of soil due to water erosion is a function of rain runoff, soil erosion, the length and grade of the slope, the soil vegetation cover, and the management of these features. Historically, the incumbent authority for the operation of the Panama Canal (Panama Canal Commission, Panama Canal Authority) kept records of sedimentation deposits from the main rivers in the Watershed, which allows for an estimation of the impact of erosion on the useful life of the reservoir. However, there has been no proper evaluation of soil loss due to erosion. The study of soils of the Regional Plan for the Development of the Interoceanic Region of Panama (1996) estimated the average potential erosion by secondary watershed using an indirect method that allows a quasi-quantitative approximation in view of the absence of data on erosion from rain when the study was performed.

Table 4-69 presents a summary of the potential erosion data reported in said study. In general, the secondary watersheds with greatest values of water erosion are associated to the regions with steepest slopes and the existence of highly erodible soils, such as those with warm rock origin in the secondary watershed of the Gatuncillo and Agua Salud Rivers—with more than 200 tons per hectare annually (ARI, 1996). When considering the specific prevailing condition of the exposed cuts in the Culebra Cut region and the Pacific Locks, with slopes greater than 45%; (and) sites with an unstable rocky stratum and scarce vegetation cover—like Cucaracha Formation—the levels of erosion are estimated at more than 280 tons per hectare annually[34].

[34] Interoceanic Regional Authority (ARI) Estimates, 1996.

Table 4-69

Erosion Potential in the Panama Canal Watershed

Secondary Watersheds	Erosion Potential
	(Ton/he/yr)
Gatun Lake Secondary Watershed	197.46
Gatun River	164.63
Mandinga River	190.7
Agua Salud River	220.07
Aguas Claras Creek	160.36
Gatuncillo River	160.36
Lago Gatun Area	66.47
Chilibre River	123.23
Chilibrillo River	99.08
Obispo River	160.25
Honda Creek	99.08
Palenque I River	108.66
Miraflores Lake Secondary Watershed	
Pedro Miguel River	115.87
Miraflores Lake Area	106.6
Average	**140.92**
Standard Deviation	**44.58**

Source: Regional Plan for the Development of the Interoceanic Region of Panama (ARI, 1996).

According to information compiled, it is estimated that the current level of erosion in the Area of Direct Impact of the Project is approximately 7.5 Tons/hectare annually, which constitutes a low level according to the FAO classification. Nevertheless, due to the existence of moderate slopes, especially in the Culebra Cut sector, it is expected that when the clearing and soil movement activities are initiated, the levels of water erosion will increase considerably.

Regarding landslides, these are produced by unstable grounds because of soil saturation, reaching the liquid limit that is the humidity content at which the soil flows down the slope. Landslides are more frequent in soils of unconsolidated materials or that is stratified in layers of varying resistance and in unstable embankments under conditions of over saturation of water. The existence of unstable bedrock due to fractures or parallel orientation to the slope, such as the Cucaracha Formation, is a factor that causes frequent landslide events (ACP, 1993-2003). Additionally, the infiltration of underground waters over cut slopes also contributes to the resulting landslide events.

The occurrence of geological faults is an important triggering factor for landslides. In the Culebra Cut region, of the Panama Canal Improvement Project, the faults are so frequent that they have been considered as the most important geological structure, with an average of one fault every 75 meters (ACP, 2002). At least two important fault systems are reported in this area—one oriented toward the northeast and the other toward the northwest. The system with the northeasterly direction was observed in the Culebra Cut and the other one is more difficult to identify since its direction is almost parallel to the Canal. These fault systems have intervened in the occurrence of landslides. Evidence shows that the stratification and anisotropy in each geological formation are of more importance than the different formations by themselves.

Landslides are recognized as a probable natural threat that may cause harm to the environment. The Panama Canal Authority Geotechnical Advisory Board, which has documented and reviewed the conditions of risk associated with the operation and improvement of the Panama Canal, has established that the areas of greatest vulnerability are:

- Adjacent to Cerro Oro “Gold Hill”;
- Culebra Cut in the areas of Cucaracha and Pedro Miguel Formations; and
- Cucaracha and Pedro Miguel Formations.

Among the historic landslides in the Panama Canal, the events of 1986 and 1996 in the Culebra Cut and Cucaracha are considered. Another significant landslide, 340 meters in length, occurred in July 1997 on Hodges Hill, followed by another one of less magnitude in September of the same year, and yet another in January 1998. The frequency of landslides only two months apart and later 4 months apart is an indicator of the problem of recurrence of these events.

Proven issues of instability have been reported at Empire West and Hodges Hill. A large number of smaller landslides have also taken place at Las Cascadas Formation to the North of Borinquen. In these cases, the foot slope was underwater. Five separate lines of slides were identified at the Cartagena Hill (ACP 2007).

In 2001, geotechnical consultants for the Panama Canal Authority designated the following active landslides in Culebra Cut:

- South Extension of Cucaracha: Revealed the greatest movement of all areas, with 934 millimeters of displacement in six years (1993 to 1999) and a displacement of 300 millimeters from 1995 to 2001;
- North of Culebra: Landslide in 1998 due to torrential rainfall;
- South of La Pita: Landslide reactivated on August 10, 1999;
- Modelo Slope: A displacement of 4 centimeters in a year was reported.
- Borinquen: Landslide in 1997.

All of these events were properly handled by the Panama Canal Authority pursuant to the Slides Control and Mitigation Plan, approved by the Geotechnical Advisory Board.

From 2001 geotechnical research, we learn that the greatest embankment instability took place in Hodges, Modelp, west of Culebra, Sardinilla, Lirio, Sardinilla, and Cucaracha. Underwater excavations in 2001 triggered a slide west of Culebra.

The three most vulnerable sites identified in the 2000 study, associated to the Cucaracha and Pedro Miguel Formations are the following:

- East Culebra Slide;

- West Culebra Slide, and
- Purple Rock Slide

Subsequently, on November 27, 2001, there was a landslide in Culebra Cut that displaced a volume of 25,000 m^3 of material, of which 7,000 m^3 fell into the navigation channel.