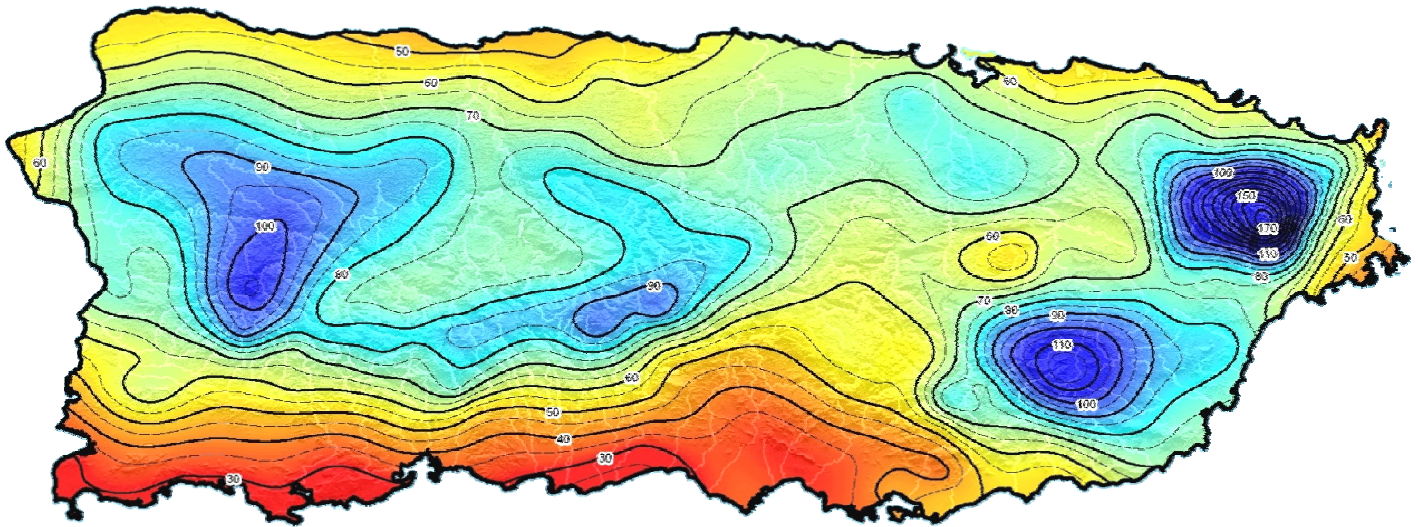


# MEAN ANNUAL RAINFALL MAP FOR PUERTO RICO



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# MEAN ANNUAL RAINFALL MAP FOR PUERTO RICO

## 1. INTRODUCTION

Several isoheytal maps have been prepared for Puerto Rico over the past four decades (Calversbert, 1970; Black and Veatch, 1971; DNER, 2003). The map published by Calversbert (1970) is presented in Figure 1, was prepared using rainfall data from 1930 to 1960. The published by DNER has significant discrepancies with station rainfall at several locations. Table 1 presents those stations with more than 10% of difference between values obtained from DNER (2003) map and those obtained from the rain gage station data. The location of these stations is presented in Figure 2. The current analysis stemmed from the desire to use the most recently available data to minimize discrepancies between maps and station data.

Table 1: Rain Gages with more than 10% of Difference from DNER (2003) Isoheytal Map.

Rain Gage	Mean Annual Rainfall (in/yr)		% Difference
	Gage Station Data	DNER Map	
San Juan City	59.1	79.0	25.2
Peñuelas 1 NE	54.7	43.7	-25.1
Toro Negro Forest	93.9	76.6	-22.5
Rio Blanco Lower	107.8	91.3	-18.1
Carite Dam	74.4	90.2	17.6
Peñuelas Salto Garzas	75.6	90.7	16.7
Lajas Substn	45.1	53.1	14.9
Caguas 1 W	54.1	63.3	14.6
Negro-Corozal	70.8	82.7	14.4
Yauco 1 NW	45.5	39.8	-14.4
Aibonito 1 S	57.7	50.8	-13.7
Jayuya	75.5	67.0	-12.7
Melania Dam	39.0	44.3	12.0
Potala	30.0	34.1	11.9
Rio Piedras Exp Stn	69.4	78.7	11.9
San Lorenzo Espino	119.0	106.8	-11.4
Sabana Grande 2 ENE	62.4	56.1	-11.3
Toro Negro Plt 2	88.9	99.9	11.0
Isabela Substn	61.3	68.5	10.5
Humacao 2 SSE	83.2	92.4	9.9

This reports presents a new isoheytal map for Puerto Rico showing contour lines of mean annual rainfall, it has been prepared based on contour curve fitting within the GIS environment, and adjusted based on geographic criteria such as proximity to the coastline, elevation, and vegetation mapping (Holdrige life zone).

### **1.1. Authorization**

Preparation of this report has been authorized by the Department of Natural and Environmental Resources (DNER) by contract # 050-08-001302.

## 2. RAINFALL DATA

Rainfall data were obtained from the US Department of Commerce National Climatic Data Center (NCDC). The NCDC database has 143 rain gages with record periods dating from 1900. A screening process was undertaken to eliminate from the analysis stations with less than 15 years of data. Other eliminated stations were those very close to other stations and with a notable difference in mean annual rainfall with other nearby gages having a longer period of record. Table 2 presents the omitted rain gages and the reasons. The rain gages used for the analysis are presented in Table 3 and Figure 3. Some rainfall stations with 14 years of record were included in the analysis because the area they are located lack of any surrounding station and the 14 years of data provides a better representation of the area.

Table 2: Rain Gages Omitted in the Analysis.

Rain Gage	Record Begin Date	Record End Date	Record Years	Rainfall (in/yr)	Reason
Bayaney	Jun-1970	Aug-1979	9	38.75	Record < 15 Years
Boca	Jul-1996	Dec-2006	10	37.21	Record < 15 Years
Caguas 2 ENE	Aug-1960	May-1967	7	50.33	Record < 15 Years
Garrochales	Sep-1965	Apr-1970	5	60.41	Record < 15 Years
Guayanilla	Jan-1955	Aug-1961	7	36.89	Record < 15 Years
Guineo RSVR	Jan-1955	Mar-1969	14	97.52	Record < 15 Years
Indiera Baja	Nov-1952	Sep-1962	10	74.62	Record < 15 Years
Jayuya 1 SE	Mar-1960	May-1981	21	60.51	Inconsistent with nearby gage stations <sup>A/</sup>
Josefa	Jan-1955	Jan-1969	14	45.32	Record < 15 Years
La Fe	Jan-1956	Mar-1969	13	72.94	Record < 15 Years
Maricao	Jan-1955	Apr-1969	14	103.8	Record < 15 Years
Naguabo 3 E	Apr-1972	May-1983	11	79.93	Record < 15 Years
Naguabo 6 W	Jan-1955	May-1967	12	90.43	Record < 15 Years
Palmarito	Mar-1963	Apr-1975	12	84.55	Record < 15 Years
Ponce Mercedita Ap	Jan-1957	Nov-1968	12	34.19	Record < 15 Years
Potala	Jan-1955	Feb-1969	14	30.02	Record < 15 Years
Rincón 2 NNW	Nov-1957	May-1968	11	57.78	Record < 15 Years
Río Piedras	Jan-1931	Dec-1961	30	76.79	Inconsistent with nearby gage stations <sup>B/</sup>
St Just	Jan-1955	Dec-1966	12	80.12	Record < 15 Years
Saltillo 2 Adjuntas	May-1981	Dec-1991	11	91.97	Record < 15 Years
Toa Baja Levitown	Jan-2005	Dec-2006	2	75.25	Record < 15 Years
Vieques Island #2	Mar-1983	Jan-1994	11	49.92	Record < 15 Years
Yauco 1 S	Jan-1955	Jun-1969	11	29.55	Record < 15 Years
Yaurel 3 NNE	Jan-1955	Mar-1969	11	45.6	Record < 15 Years

<sup>A/</sup> Inconsistent with gage station Jayuya (Period of Record 1909-2002, Rainfall of 75.5 in/yr).

<sup>B/</sup> Inconsistent with gage station Río Piedras Exp Stn (Period of Record 1959 - 2006, Rainfall of 69.37 in/yr).

Table 3: Rain Gages Used to Generate Isoheytal Map.

Rain Gage	Record Begin Date	Record End Date	Rainfall (in/yr)
Aceituna	Jan-1955	Dec-2006	76.90
Adjuntas 1 NW	Jan-1955	Dec-2006	78.29
Adjuntas Substn	Jan-1970	Dec-2006	73.62
Aguirre	Jan-1931	Oct-1966	42.89
Aguirre	Apr-1955	Dec-2006	40.47
Aibonito 1 S	Jan-1906	Dec-2006	57.72
Arecibo 3 Ese	Jul-1931	Jan-1999	54.39
Arecibo Obsy	Feb-1980	Dec-2006	82.64
Barceloneta 2	Jan-1955	May-1990	53.34
Barceloneta 3 SW	Sep-1990	Dec-2006	60.39
Barranquitas	Jan-1955	Dec-1991	57.38
Benavente-Hormigueros	Aug-1973	Aug-2002	59.95
Borinquen AP	Feb-1974	Dec-2006	53.66
Cabo Rojo	Jan-1955	Aug-1969	56.41
Cacaos-Orocovis	May-1981	Dec-2006	82.76
Caguas	May-1899	Aug-1960	61.25
Caguas 1 W	Mar-1970	Mar-1995	54.08
Calero Camp	Jan-1955	Dec-2006	56.29
Cambalache Exp Forest	Jan-1932	Feb-1966	51.00
Candelaria Toa Baja	Jan-1955	May-1973	78.14
Candelaria Toa Baja	Oct-1973	Aug-1995	74.74

Rain Gage	Record Begin Date	Record End Date	Rainfall (in/yr)
Canóvanas	Jan-1955	Dec-2006	74.37
Caonillas Utuado	Jan-1955	Nov-1987	73.32
Caonillas Villalba	Jan-1955	Sep-1969	55.12
Carite Dam	Jan-1955	Apr-1980	74.37
Carite Plt 1	Jan-1955	Mar-1980	72.83
Cataño	Jan-1955	May-1976	69.17
Cayey 1 E	Jan-1955	Jun-2001	58.32
Central San Francisco	Jan-1955	Jun-1996	31.04
Cerro Gordo Ciales	Oct-1969	Sep-1997	82.26
Cerro Maravilla	Apr-1969	Dec-2006	94.46
Cidra 1 E	Sep-1899	Jun-1994	66.49
Coamo 2 SW	Jan-1955	Dec-2003	36.40
Coloso	Oct-1899	Dec-2006	80.29
Comerío Falls Plt 2	Feb-1959	May-1974	65.74
Corozal Substn	Jan-1931	Dec-2006	75.06
Corral Viejo	Apr-1970	Dec-2006	59.18
Culebra Island	Jan-1920	Jul-1975	33.08
Dorado 2 Wnw	Jan-1931	May-2006	65.21
Dos Bocas	Jan-1937	Dec-2006	76.82
Ensenada 1 W	Jan-1955	Dec-2006	30.76
Fajardo	Jan-1931	Jan-1996	64.81

Rain Gage	Record Begin Date	Record End Date	Rainfall (in/yr)
Garzas	Jan-1939	Jan-1981	86.16
Guajataca Dam	Jan-1955	Dec-2006	71.13
Guavate Camp	Dec-1969	Jun-1994	99.56
Guayabal	Jan-1955	Dec-2006	49.85
Guayama 2E	Jan-1911	Dec-2006	52.61
Gurabo	Apr-1946	May-1967	63.75
Gurabo Substn	Mar-1956	Dec-2006	64.19
Hacienda Constanza	Oct-1969	Dec-2006	73.89
Hato Arriba Arecibo	Feb-1974	Aug-1994	55.08
Humacao 2 SSE	Jan-1931	Jan-1996	83.19
Indiera Alta	Oct-1962	Jun-1990	76.42
Isabela Substn	Jan-1901	Dec-2006	61.30
Jájome Alto	Jan-1955	Dec-2006	77.47
Jayuya	Apr-1909	Aug-2002	75.50
Juana Díaz Camp	Jan-1931	Dec-2006	42.21
Juncos 1 SE	Jan-1931	Dec-2006	66.87
Lajas Substn	Jan-1900	Dec-2006	45.14
La Muda Caguas	Sep-1971	Jun-1994	78.92
Lares	Jun-1903	Dec-1991	93.21
Los Caños	Jan-1955	Aug-1973	62.63
Magüeyes Island	Jan-1959	Nov-2006	28.68
Manatí 2 E	Jan-1900	Dec-2006	62.23
Maricao 2 SSW	May-1969	Dec-2006	95.33

Rain Gage	Record Begin Date	Record End Date	Rainfall (in/yr)
Maricao Fish Hatchery	Jan-1955	Dec-2006	98.6
Matrullas Dam	Jan-1955	Apr-1981	86.64
Maunabo	May-1899	Apr-2003	73.95
Mayagüez City	Jan-1957	Dec-2006	75.08
Mayagüez AP	Jan-1900	Dec-2006	76.16
Melania Dam <sup>AV</sup>	Jan-1955	Jan-1969	39.03
Mona Island	Jan-1955	Aug-1974	35.91
Mona Island 2	Feb-1980	Dec-2006	39.09
Monte Bello Manatí	Oct-1969	Sep-2001	61.62
Mora Camp	Jan-1955	Dec-2006	58.9
Morovis 1 N	Feb-1956	Dec-2006	71.37
Negro-Corozal	Jan-1976	Dec-2006	70.75
Paraíso	Jan-1956	Dec-2006	98.21
Patillas	Apr-1982	Jun-2003	57.79
Patillas Dam	Jan-1931	Jan-1969	70.23
Peñuelas Salto Garzas	Mar-1971	Dec-2003	75.55
Peñuelas 1 NE	Jan-1955	Feb-1971	54.69
Pico del Este	Oct-1969	Jun-2005	174.38
Ponce 4 E	Apr-1954	Dec-2006	35.12
Ponce City	Jul-1970	Aug-1998	29.45
Puerto Real	Jan-1955	Aug-2001	48.04
Quebradillas	Jan-1955	Sep-2000	55.69
Rincón	Jun-1968	Nov-2006	55.41



Rain Gage	Record Begin Date	Record End Date	Rainfall (in/yr)
Río Blanco Lower	Jan-1955	Dec-2006	107.83
Río Blanco Upper	Jan-1955	Mar-1974	161.78
Río Cañas	Jan-1955	Dec-1969	36.66
Río Grande el Verde	Feb-1956	Dec-1987	96.36
Río Jueyes <sup>A/</sup>	Jan-1955	Jan-1969	31.13
Río Piedras Exp Stn	Jan-1959	Dec-2006	69.37
Roosevelt Roads	Jul-1959	Mar-2004	51.61
Sabana Grande 2 ENE	May-1977	Dec-2006	62.39
Sabater <sup>A/</sup>	Jan-1955	Jan-1969	37.78
San Cristóbal	Jan-1956	Mar-1972	76.33
San Germán 4 W	Nov-1904	Jul-1973	64.37
San Juan City	Jan-1955	May-1977	59.07
San Juan Intl Ap	Jan-1956	Dec-2006	54.36
San Lorenzo 3S	Mar-1966	Dec-2006	98.57
San Lorenzo Espino <sup>A/</sup>	Jan-1945	Jun-1959	118.96

Rain Gage	Record Begin Date	Record End Date	Rainfall (in/yr)
San Lorenzo Farm 2 NW	Jan-1955	Sep-1988	72.61
San Sebastián 2 WNW	Apr-1955	Oct-1997	91.25
Santa Isabel 2 ENE	Jan-1955	Dec-2006	34.50
Santa Rita	Jan-1955	Dec-2006	33.30
Toa Baja 1 SSW	Jan-1955	Aug-1994	68.01
Toro Negro Forest	Aug-1982	Dec-2006	93.85
Toro Negro PLT 2	Jan-1955	Jul-1981	88.94
Trujillo Alto 2 SSW	Feb-1957	Dec-2006	71.96
Utuaedo	Jan-1931	Jul-1998	73.36
Vieques Island	Jan-1955	Sep-1976	42.68
Villalba 1 SE	Jan-1955	Dec-2006	64.19
Yabucoa 1 NNE	Jan-1955	Mar-1995	79.11
Yauco 1 NW	Dec-1981	Dec-2006	45.52

<sup>A/</sup> Station with 14 years of record included in the analysis.

## 2.1. Isoheytal Map

The NCDC rainfall gage station data were used to interpolate a surface within the Arc-GIS environment using *spline curves* to create the initial isoheytal countours. *Spline* algorithms can create very smooth surfaces from moderately detailed data and provide exact interpolation within smoothing limits. This method is best suitable for gently varying surfaces, such as rainfall.

The initial contour lines were then adjusted based on coastline proximity, elevation and vegetation mapping. The resulting contours were checked against USGS streamgage data, comparing rainfall and runoff per unit of watershed area to reveal any unusual discrepancies. The rainfall-runoff relationship resulting from the final isoheytal map is presented in Figure 4. The resulting rainfall surface, rainfall contour and rainfall surface with contours maps are presented in Figure 5, Figure 6 and Figure 7. respectively.

The following physical parameters were used to realign rainfall contours in areas of sparse gage data:

- Contours adjacent to the ocean were adjusted to lie roughly parallel to the coastline, instead of locally curving around coastal rain gage stations;
- Contours along the Cordillera Central were adjusted to run generally parallel to the mountains peaks to better reflects orographic effects; and
- Contours were also checked against Holdridge Life Zone vegetation map, since this mapping system reflects long-term rainfall patterns (Ewel and Whitmore, 1973).

### **3. REFERENCES**

Calvesbert, R.J., 1970, *Climate of Puerto Rico and U.S. Virgin Islands*, revised: U.S. Environmental Science Services Administration, *Climatology of the United States*.

Ewel, J.J. and Whitemore, J.L., 1973. *The Ecological Life Zones of Puerto Rico and the U.S. Virgin Islands*. Puerto Rico.

# Figures

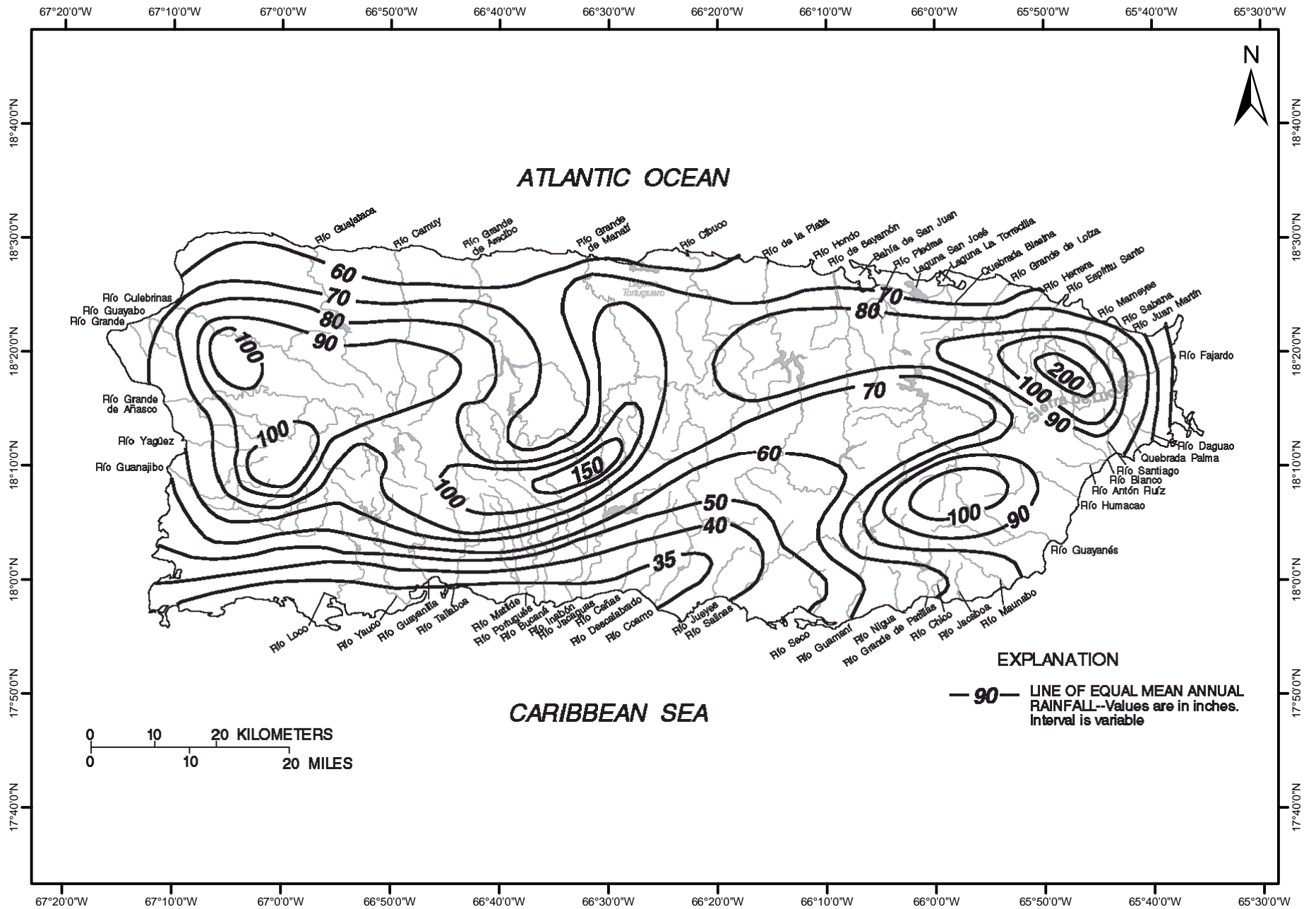


Figure 1: Mean annual rainfall, prepared using rainfall data from 1931 to 1960 (Calversbert, 1970).

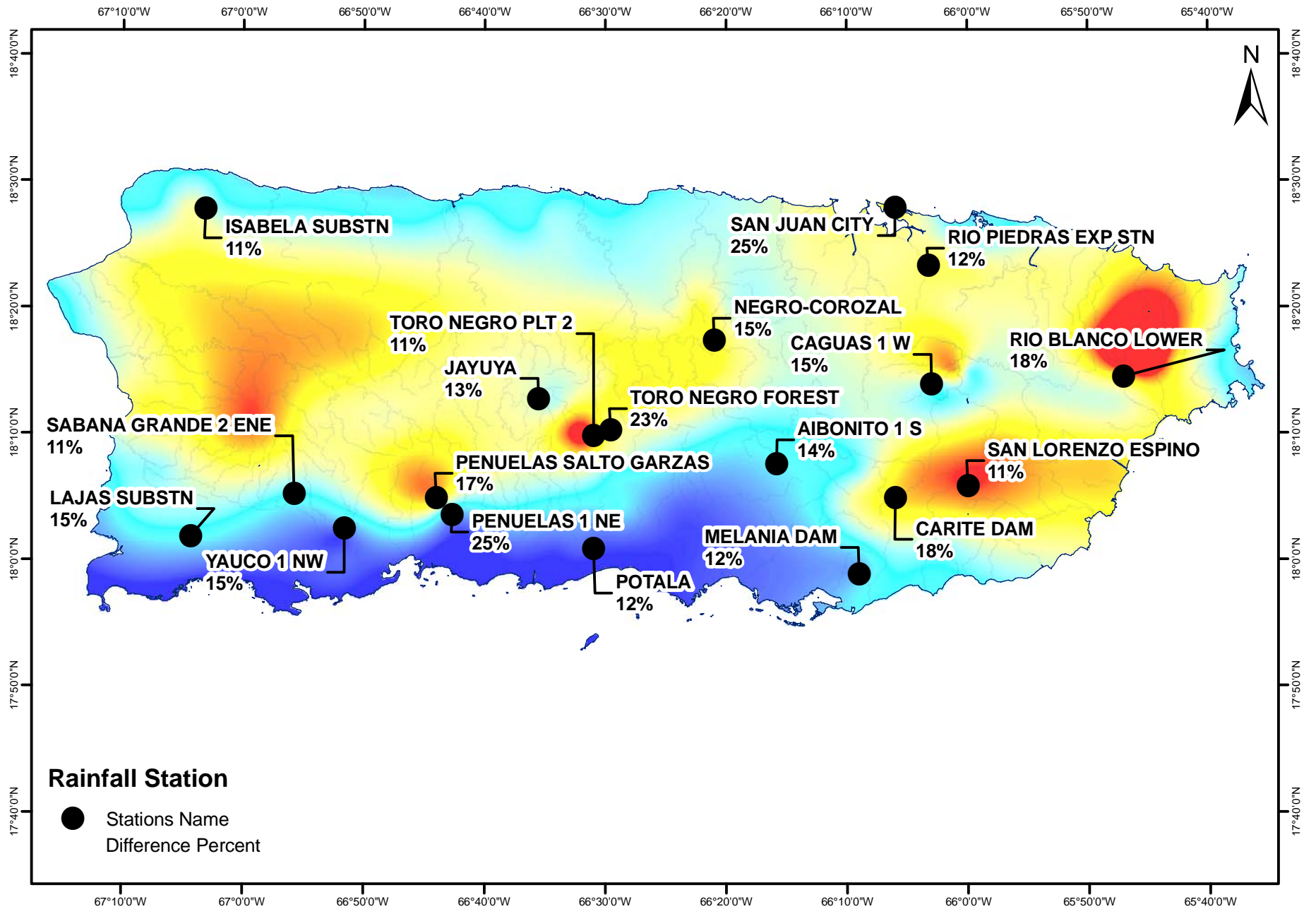
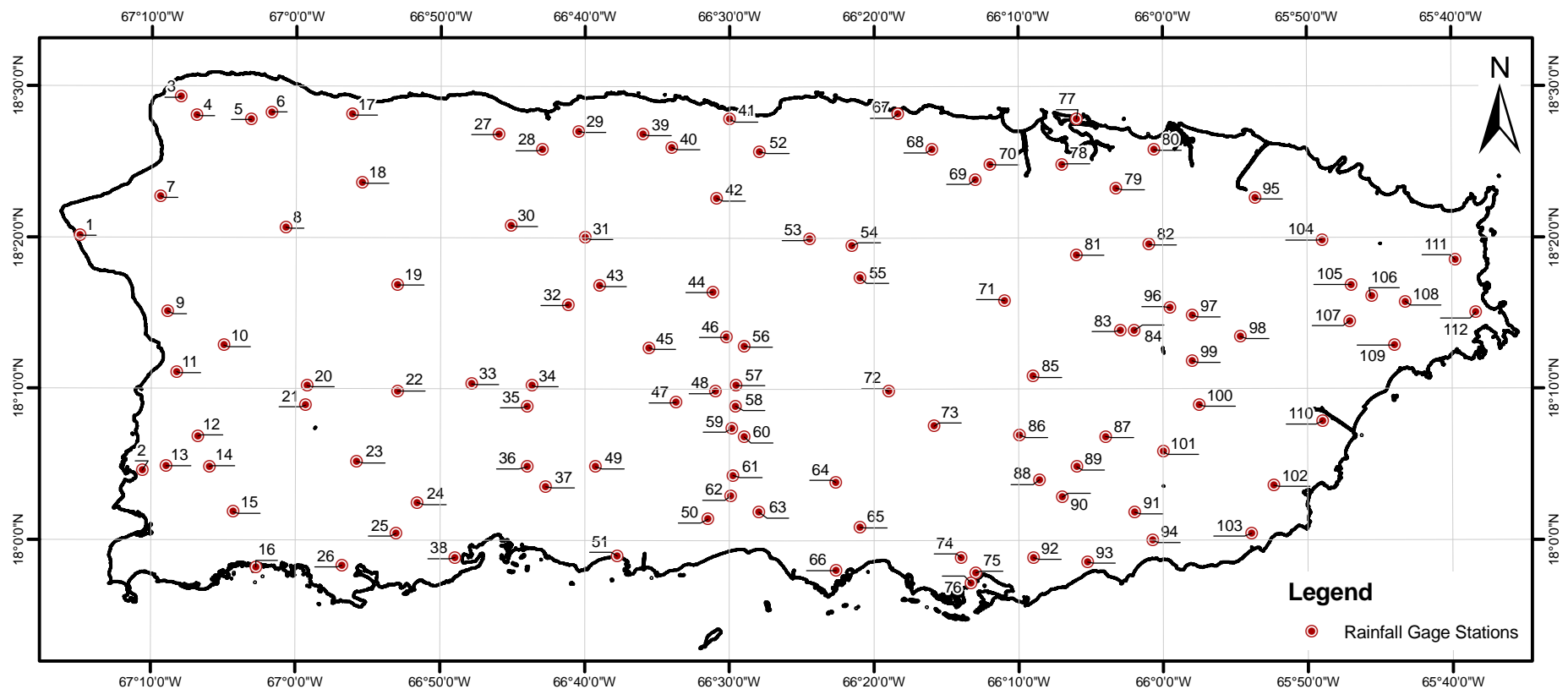


Figure 2: Rain gages with more than 10% difference in mean annual rainfall between station data and DNER (2003) rainfall map.



<u>Station Name</u>	<u>ID</u>	<u>Station Name</u>	<u>ID</u>	<u>Station Name</u>	<u>ID</u>	<u>Station Name</u>	<u>ID</u>	<u>Station Name</u>	<u>ID</u>	<u>Station Name</u>	<u>ID</u>		
Rincón	1	Guajataca Dam	18	Garzas	35	Manatí 2 E	52	Candelaria Toa Baja	69	Cayey 1 E	86	Maunabo	103
Puerto Real	2	Lares	19	Peñuelas 1 NE	36	Morovis 1 N	53	Candelaria Toa Baja	70	Guavate Camp	87	Río Grande el Verde	104
Borinquen AP	3	Maricao Fish Hatchery	20	Peñuelas Salto Garzas	37	Corozal Substn	54	Comerio Falls Plt 2	71	Jajome Alto	88	Río Blanco Upper	105
Calero Camp	4	Maricao 2 SSW	21	Central San Francisco	38	Negro-Corozal	55	Barranquitas	72	Carite Dam	89	Pico del Este	106
Isabela Substn	5	Indiera Alta	22	Cambalache Exp Forest	39	Matrullas Dam	56	Aibonito 1 S	73	Carite Plt 1	90	Río Blanco Lower	107
Mora Camp	6	Sabana Grande 2 ENE	23	Barceloneta 3 SW	40	Toro Negro Forest	57	Sabater	74	Patillas Dam	91	Paraíso	108
Coloso	7	Yauco 1 NW	24	Barceloneta 2	41	Aceituna	58	Aguirre	75	Melania Dam	92	San Cristóbal	109
San Sebastián 2 WNW	8	Santa Rita	25	Monte Bello Manatí	42	Villalba 1 SE	59	Aguirre	76	Guayama 2E	93	Humacao 2 SSE	110
Mayagüez City	9	Ensenada 1 W	26	Caonillas Utuado	43	Caonillas Villalba	60	San Juan City	77	Patillas	94	Fajardo	111
Hacienda Constanza	10	Hato Arriba Arecibo	27	Cerro Gordo Ciales	44	Guayabal	61	Cataño	78	Canóvanas	95	Roosevelt Roads	112
Mayagüez AP	11	Los Caños	28	Jayuya	45	Juana Díaz Camp	62	Río Piedras Exp Stn	79	Gurabo Substn	96	Vieques Island	113
Benavente-Hormigueros	12	Arecibo 3 Ese	29	Cacaos-Orocovis	46	Río Cañas	63	San Juan Intl Ap	80	Gurabo	97	Culebra Island	114
Cabo Rojo	13	Arecibo Obsy	30	Cerro Maravilla	47	Coamo 2 SW	64	La Muda Caguas	81	Juncos 1 SE	98		
San Germán 4 W	14	Dos Bocas	31	Toro Negro PLT 2	48	Río Jueyes	65	Trujillo Alto 2 SSW	82	San Lorenzo Farm 2 NW	99		
Lajas Substn	15	Utuado	32	Corral Viejo	49	Santa Isabel 2 ENE	66	Caguas 1 W	83	San Lorenzo 3S	100		
Magüeyes Island	16	Adjuntas Substn	33	Ponce 4 E	50	Dorado 2 Wnw	67	Caguas 1 W	84	San Lorenzo Espino	101		
Quebradillas	17	Adjuntas 1 NW	34	Ponce City	51	Toa Baja 1 SSW	68	Cidra 1 E	85	Yabucoa 1 NNE	102		

Figure 3: National Climatic Data Center rainfall gage stations used to generate mean annual rainfall map.

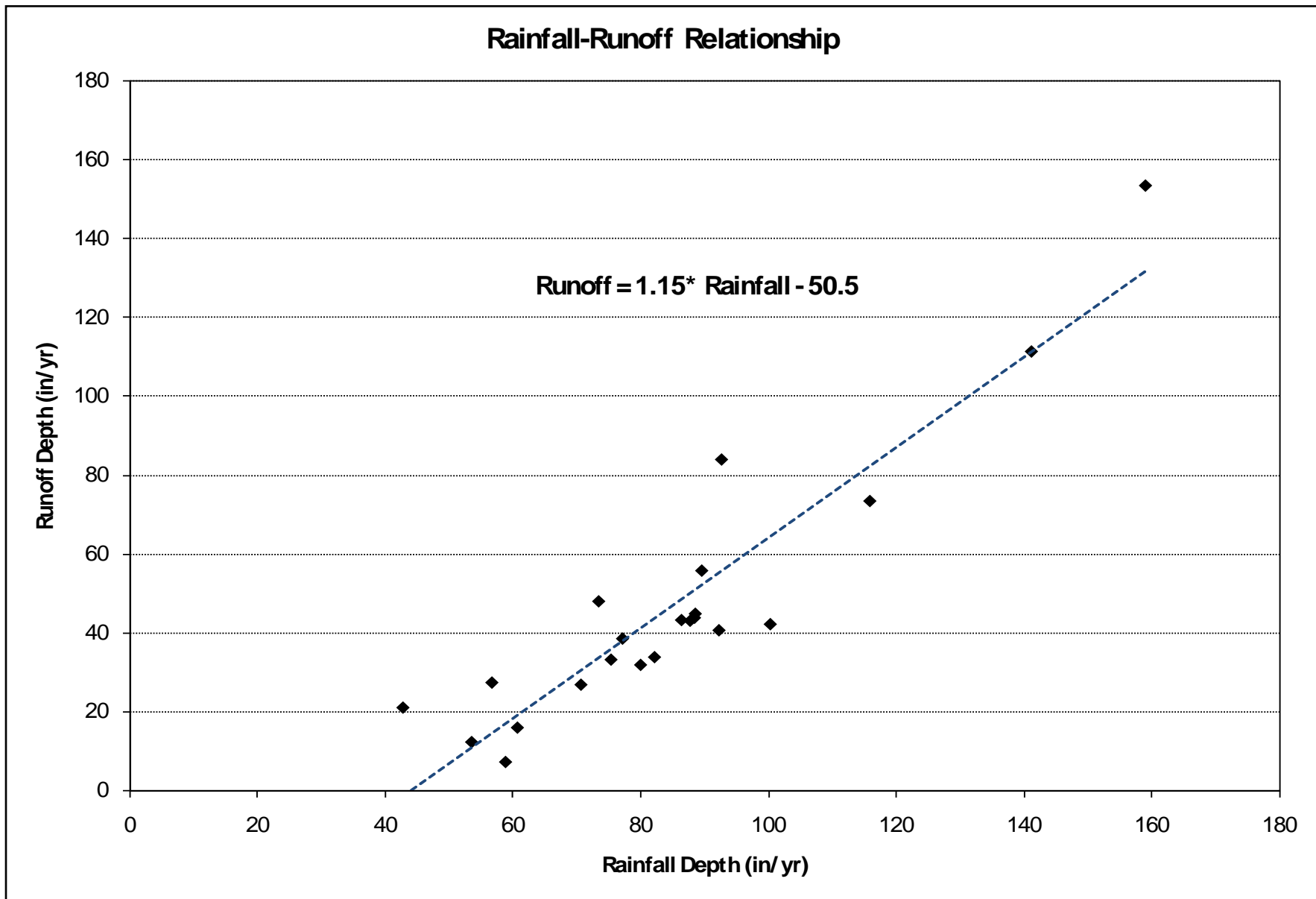
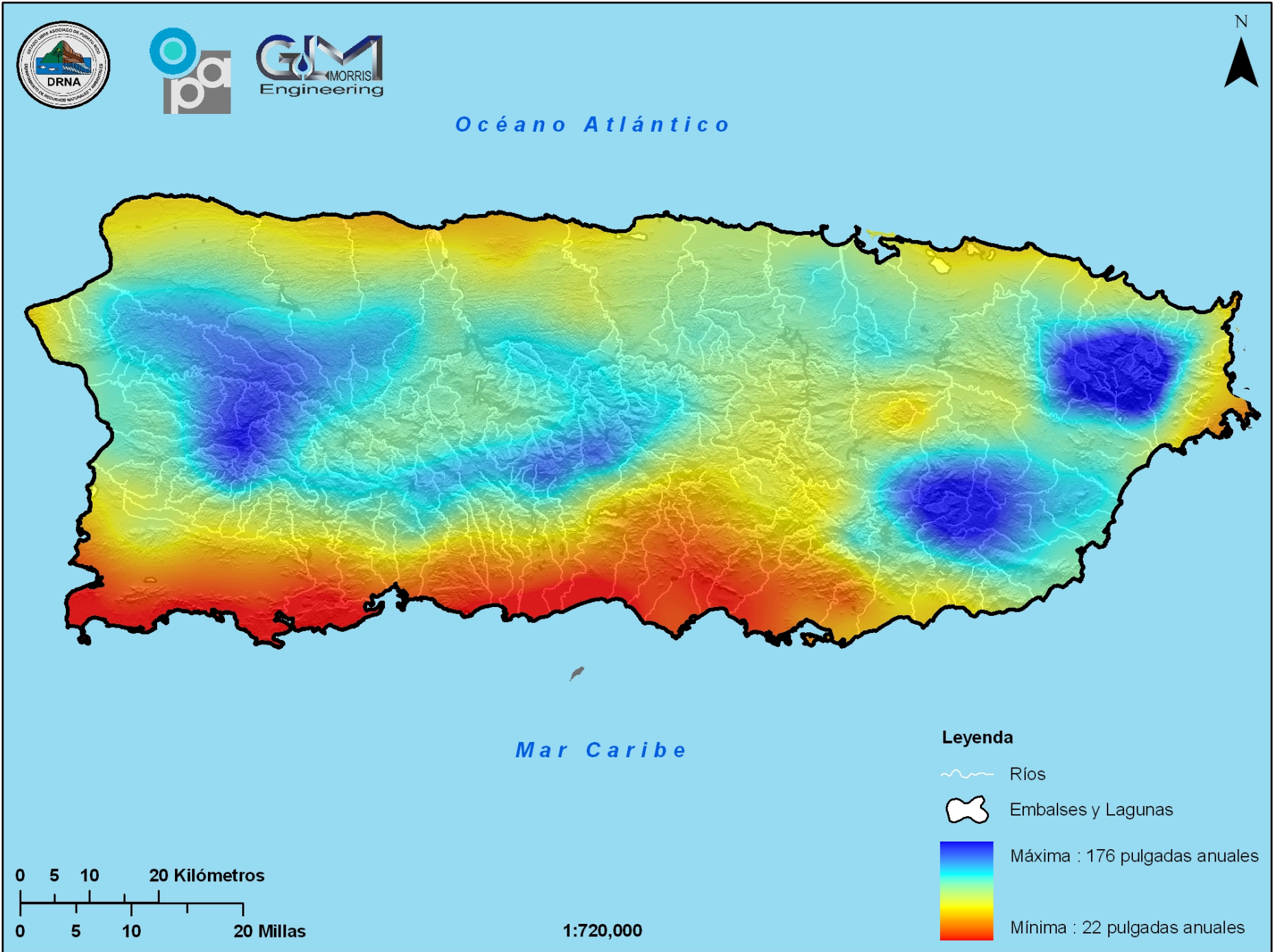


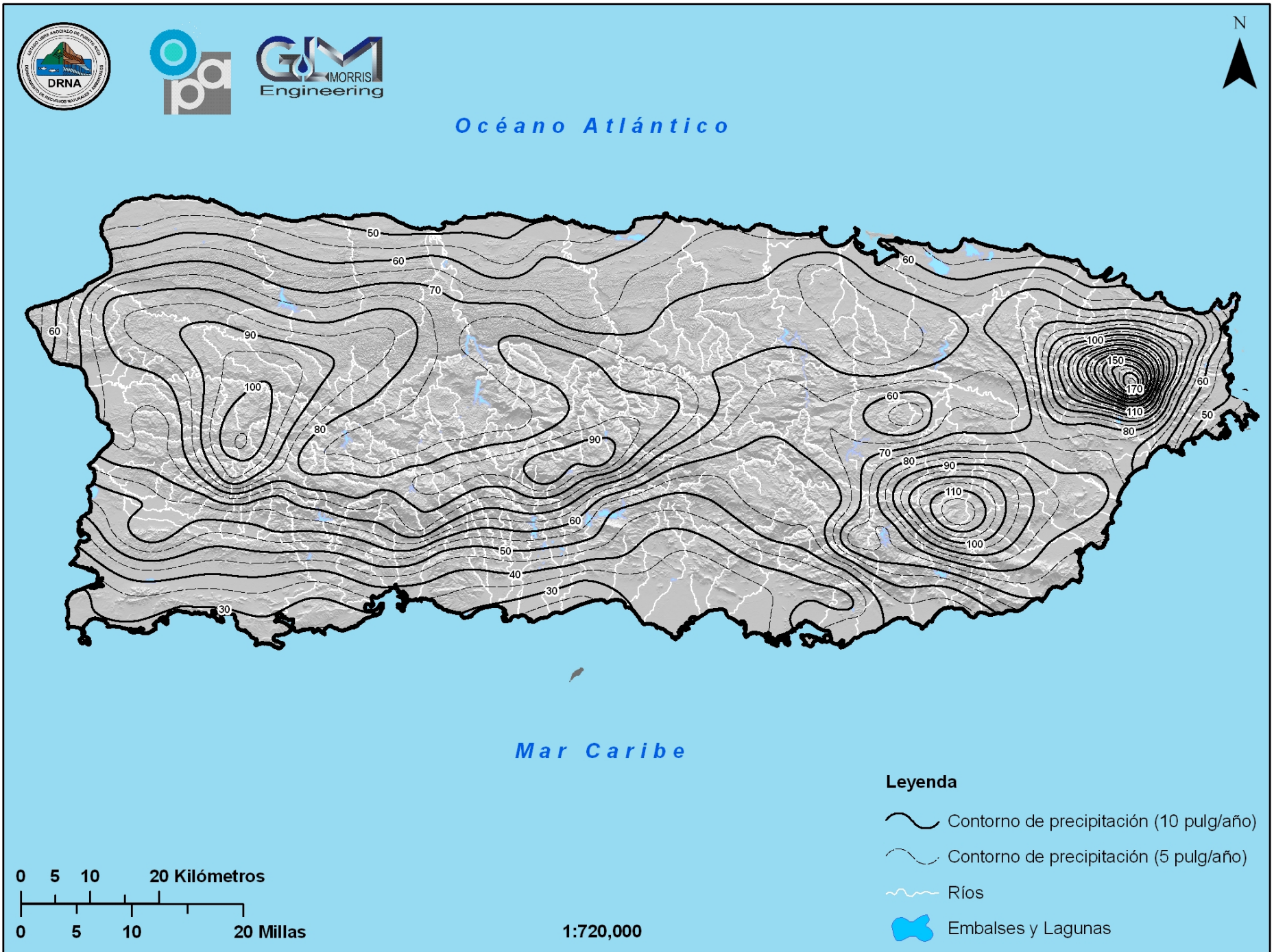
Figure 4: Rainfall-runoff relationship resulting from the final mean annual rainfall map.





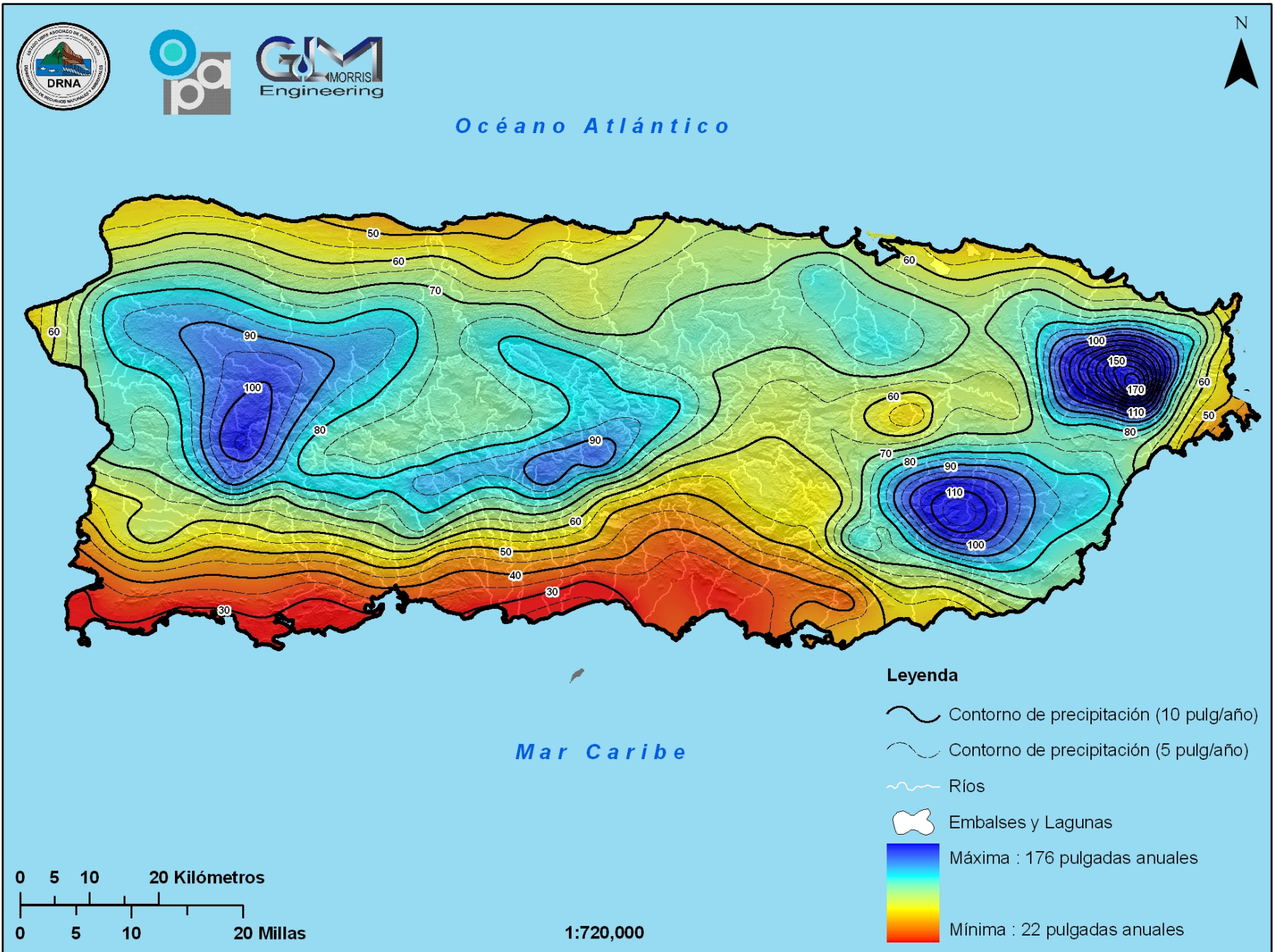
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Figure 5: Mean annual rainfall surface map for Puerto Rico.



Preparado por GLMorris Engineering para DRNA, 2009

Figure 6: Mean annual rainfall contours map for Puerto Rico.



Preparado por GLMorris Engineering para DRNA, 2009

Figure 7: Mean annual rainfall surface and contours map for Puerto Rico.