Limestone-alluvium boundary where the alluvial aquifer behaves as a barrier to horizontal flow (Botbol, 1984; White, 1980).

GROUND-WATER IN THE BASINS

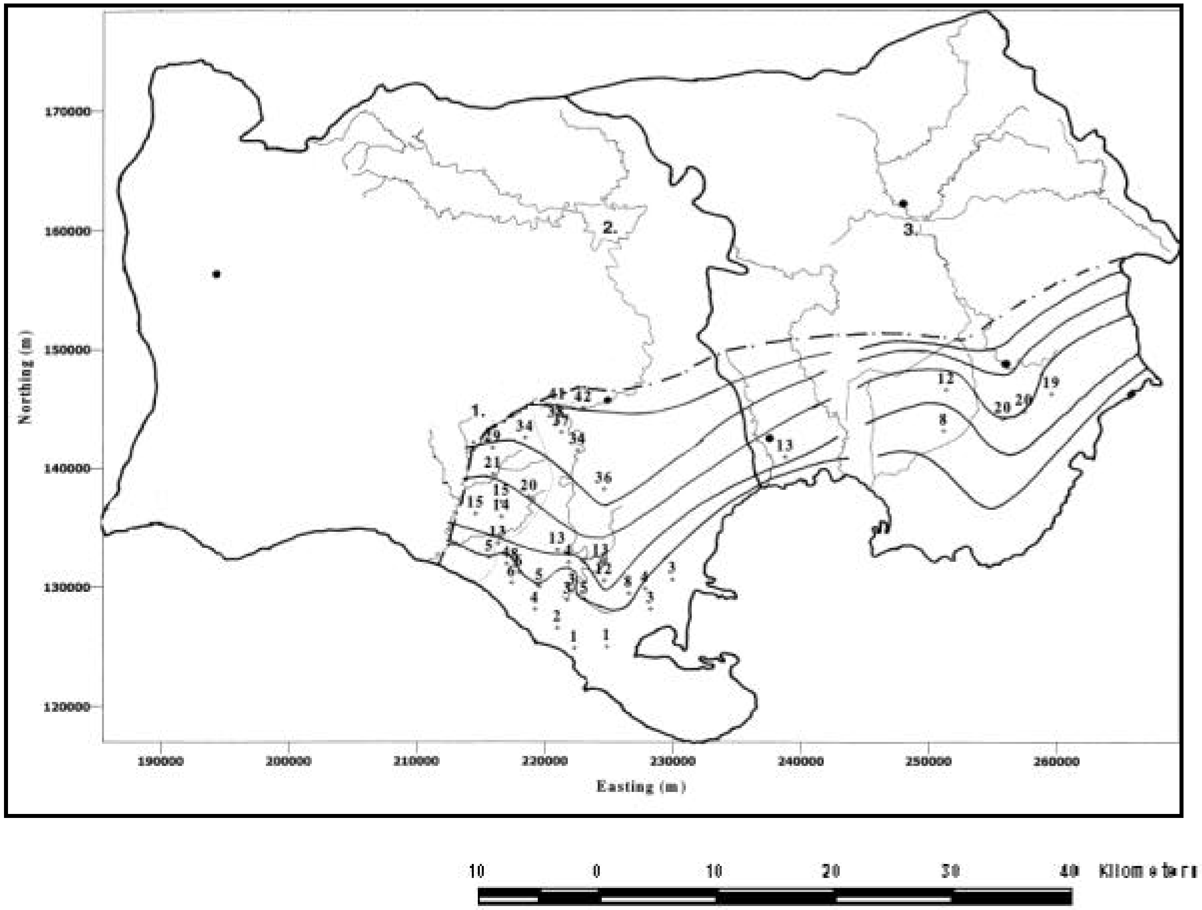
Water Table

Water table gradients are relatively steep near upland areas of the Central Inlier. Hydraulic heads within the alluvial aquifer are typically lower than those of the underlying White Limestone aquifer. The source of groundwater in the alluvial aquifer appears to be from vertical leakage via White Limestone aquifer and indirectly by infiltration of irrigation water drawn from wells developed in the White Limestone. Water level monitoring of selected wells is an ongoing program of the WRAJ. Contoured maps of 1998 water levels recorded in the White Limestone and alluvial aquifers are shown in Figures 3.11-3.12.

Water level data were obtained from irregular-spaced wells located in both aquifers. No well data are available for the western highlands because wells drilled there typically yielded little or no water. Consequently, depth to water was extrapolated on the basis of known depths to water in other regions of similar geology (Williams and Williamson, 1989).

Structurally-Controlled Ground-Water Flow

Joints, fractures, and solution openings provide avenues through which ground-water flow is channeled (Kiersch and Hughes, 1952). Minor fault and major fracture traces are favorable sites for production wells in the Rio Cobre and Rio Minho-Milk



EXPLANATION

——10 —— **MEASURED WATER TABLE CONTOUR –** Shows altitude of December 1997 water levels. Source of data is WRAJ. Contour Interval is variable.Datum is mean sea level

● **OBSERVATION WELL** Well used as control point to construct potentiometric surface map. Number shows measured water level

▬ Physiographic boundary of study area

- - White Limestone – alluvium contact

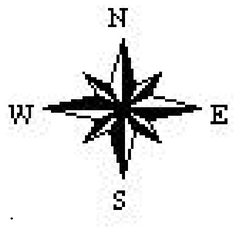
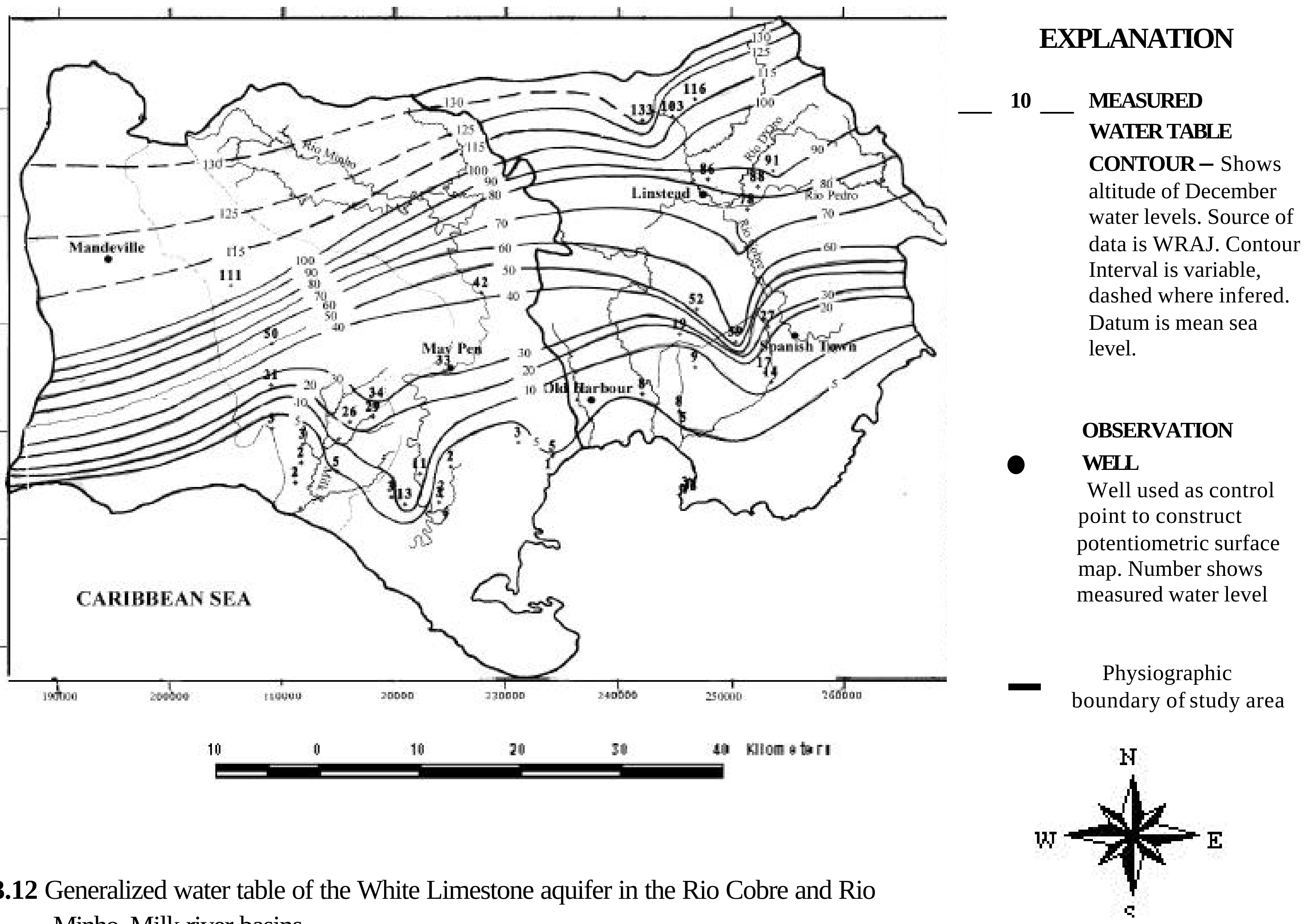


Figure 3.11 Generalized water table of the alluvial aquifer in the Rio Cobre and Rio Minho-Milk river basins, 1 – Milk River, 2 – Rio Minho, and 3 – Rio Cobre.



EXPLANATION

10 — **MEASURED WATER TABLE CONTOUR** – Shows altitude of December water levels. Source of data is WRAJ. Contour Interval is variable, dashed where infered. Datum is mean sea level.

● **OBSERVATION WELL** Well used as control point to construct potentiometric surface map. Number shows measured water level

▬ Physiographic boundary of study area

Figure 3.12 Generalized water table of the White Limestone aquifer in the Rio Cobre and Rio Minho-Milk river basins.

River basins. Oxygen and hydrogen isotope data have confirmed that major well production areas of the Rio Minho-Milk River basin are located in lowland coastal areas where there is isotopic modification (oxygen depletion of – $1.4^{0}/_{00}$) by evaporative processes (Mullings, 1993). This implies the waters here do not originate from the recharge zones located in the upper region of the basin, but rather from the underlying wells in the White Limestone. The White Limestone-alluvium contact is fault-controlled and crosses the southern section of the Rio Cobre and Rio Minho-Milk river basins (Figure 3.13). The White Limestone aquifer is unconfined where it is exposed along the northern half (upland regions) and western sections of the study area and becomes confined as it dips beneath the alluvium in the lower half of the region. The coastal margins of the island are mainly down-faulted blocks with the fault planes bounding these blocks resulting in several barriers or dams to ground-water flow. This accounts for the relatively high dry season stream flows, typical of rivers draining areas where the White Limestone aquifer outcrops.

In the Rio Cobre basin, the Cavaliers fault (strike-slip), though not a direct continuation of the Crawle River-Rio Minho fault, strikes E – W and is located south of Bog Walk (Figure 2.8). White (1985) described the Upper Rio Cobre basin as a closed inland groundwater basin with no underflow into or out of the aquifer. Surface water leaves the basin only as surface flow to the Rio Cobre. In the Rio Minho-Milk River basin, a northwest-southeast trending graben bisects the western boundary of the study area. The alluvium thickens abruptly and fills this graben between Kemps Hill and Portland Ridge along the Vere Plains (Figure 3.13, Fig 1.1a). Two high-angle faults border the alluvium where the White Limestone is uplifted at Round Hill and Portland Ridge (Figure 3.13). These faults represent the South Coast fault to the north side of the alluvial graben and the Portland Ridge fault to the south side (Figure 3.13). Gravity profiles of Free Air and Bouguer anomalies constructed by Wadge et al. (1983) support the abrupt thickening of the alluvium at Vere Plains. Gravity anomalies steepen between values of 42 to 54 milligals in and around the eastern end of the South Coast fault and Portland Ridge fault, whereas a relatively constant value of 40 milligals is measured across the Vere Plains (Figures 3.14a and 3.15). A two-dimensional model of this gravity profile is shown in Figure 3.14b.

The South Coast Fault Zone (SCFZ) that crosses the lower Rio Minho-Milk River basin has been the subject of both seismic (NASA, 1971) and hydrochemical (Mullings et al., 1993) investigations. The SCFZ may act as a permeable vertical conduit for flow of seawater from the ocean to the White Limestone aquifer. Upward flow from the White Limestone induced by irrigation pumping has resulted in subsequent contamination of the alluvial aquifer (Figure 3.8). Numerous wells in both the alluvium and White Limestone aquifer have been have been abandoned or shut down because of contamination from increased salinity caused by excessive pumpage within the fault zone. Wallace Evans and Partners (1985) reported the occurrence of increasing salinity in a number of limestone and alluvium wells in southern Clarendon at Monymusk (Figure 3.16). Howard and Mullings (1995) suggest that the presence of a seawater wedge extending beneath the alluvium graben may also be the source of the salinity in the alluvial wells in the lower

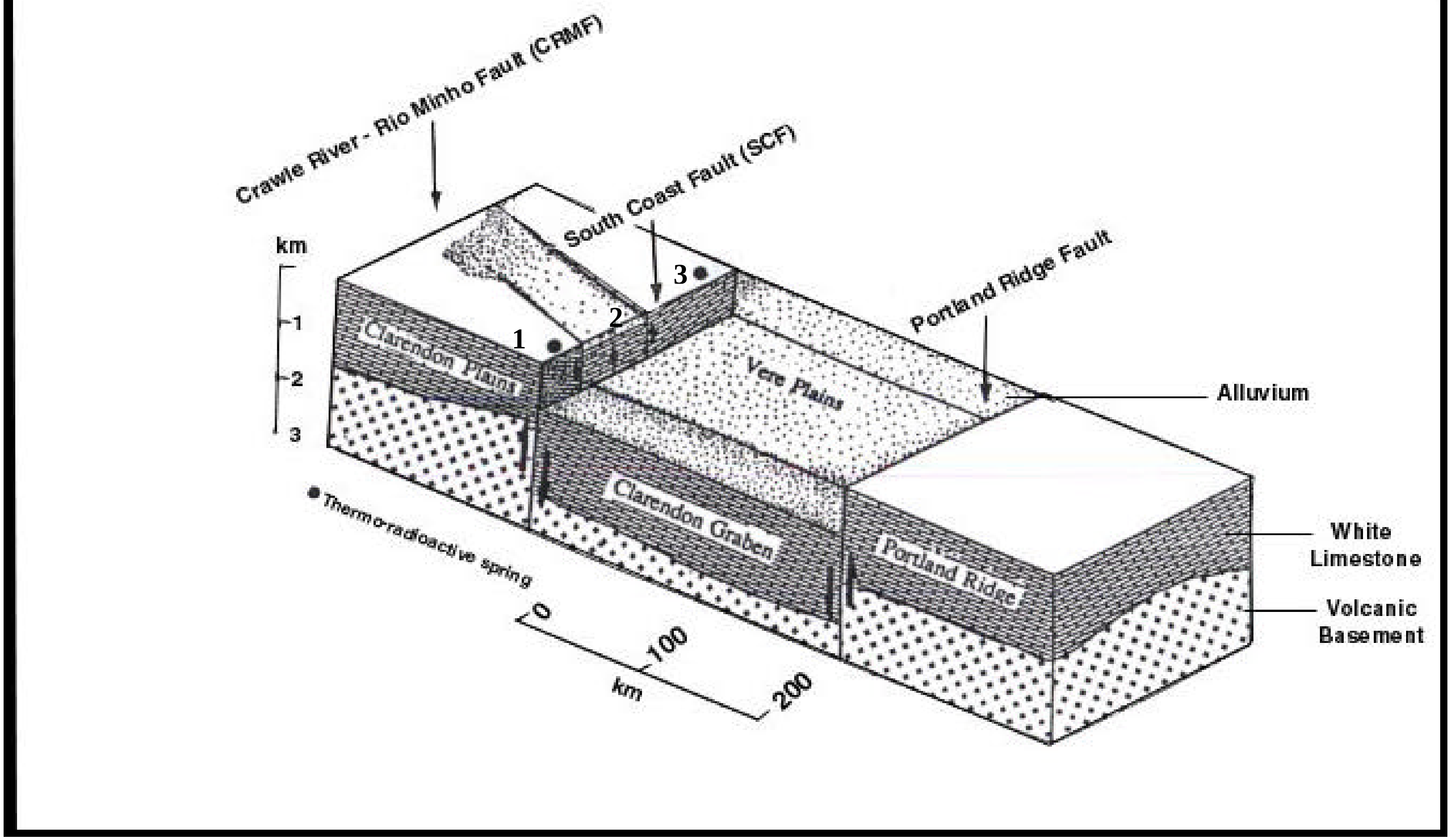


Figure 3.13 Cross-section across the lower Rio Minho – Milk River Basin (Data from Wadge et al., (1983), United Nations Diversity Program – Food and Agricultural Organization report (1974)). 1- Round Hill, 2 – Kemps Hill, 3 – Brazilletto Mountains.

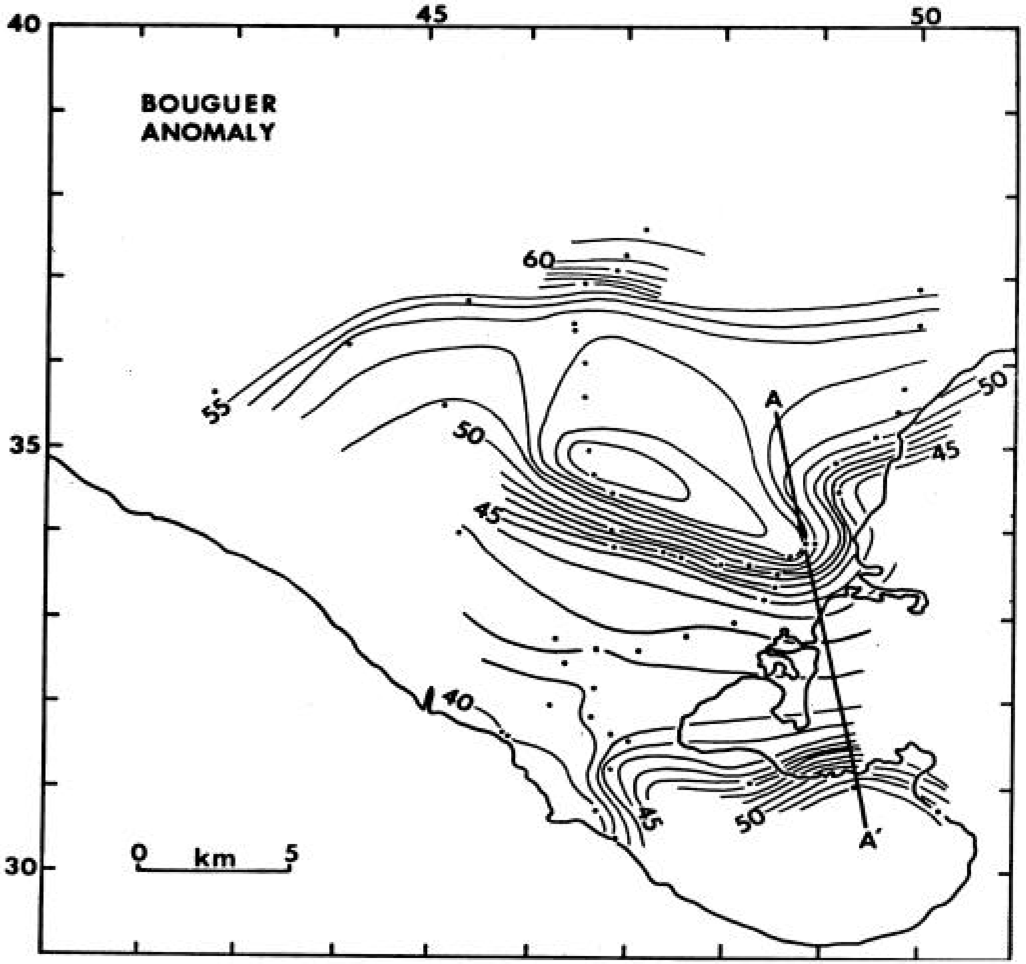


Figure 3.14a Map of Vere Plains in the lower Rio Minho-Milk River basin showing Bouguer gravity contoured at intervals of 5 milligals. Black dots represent gravity stations and A - A' is the gravity anomaly profile used for a two-dimensional model below.

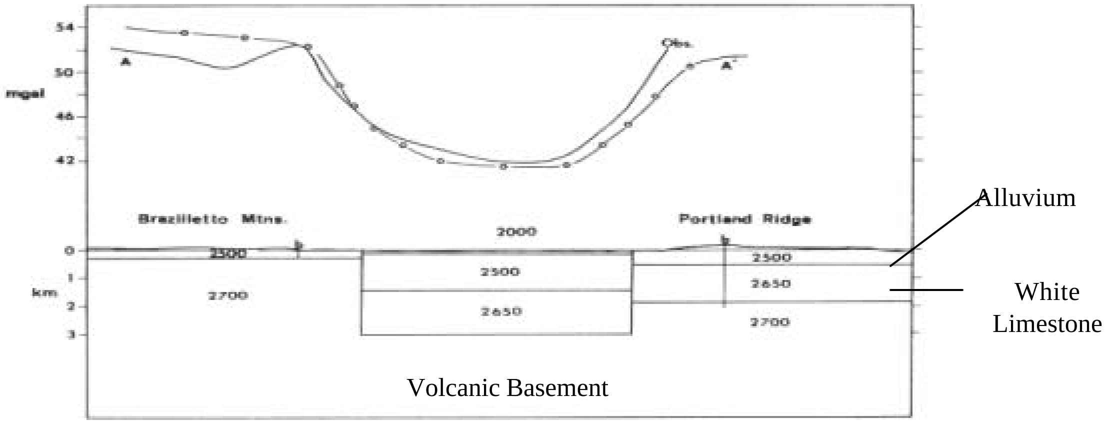


Figure 3.14b Two-dimensional structure model corresponding to Bouguer anomaly profile A-A'.

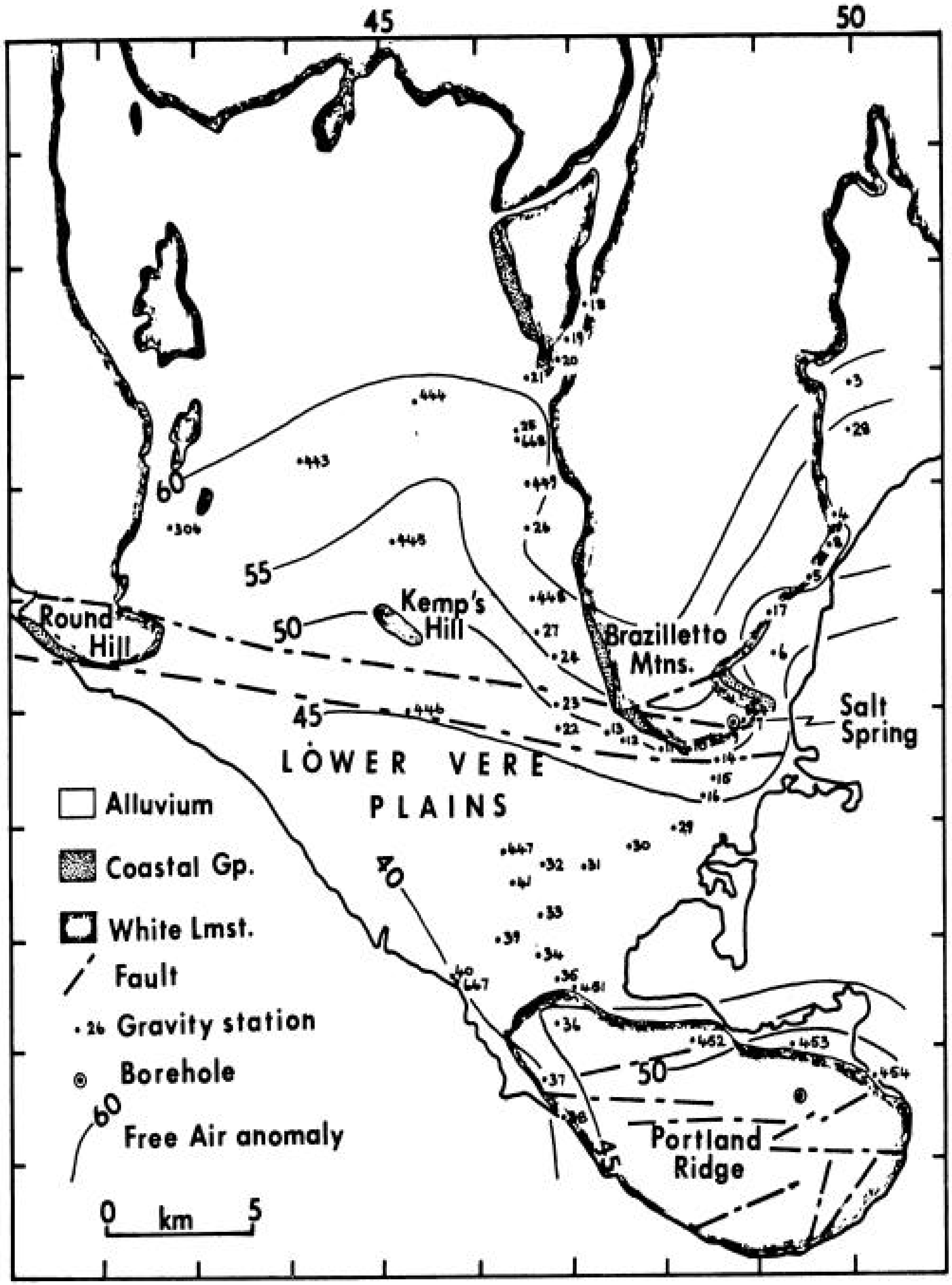


Figure 3.15 Simplified geological map of the Vere Plains in the lower Rio Minho-Milk River basin showing Free Air gravity anomalies contoured at intervals of 5 milligals. (Wadge, 1983).

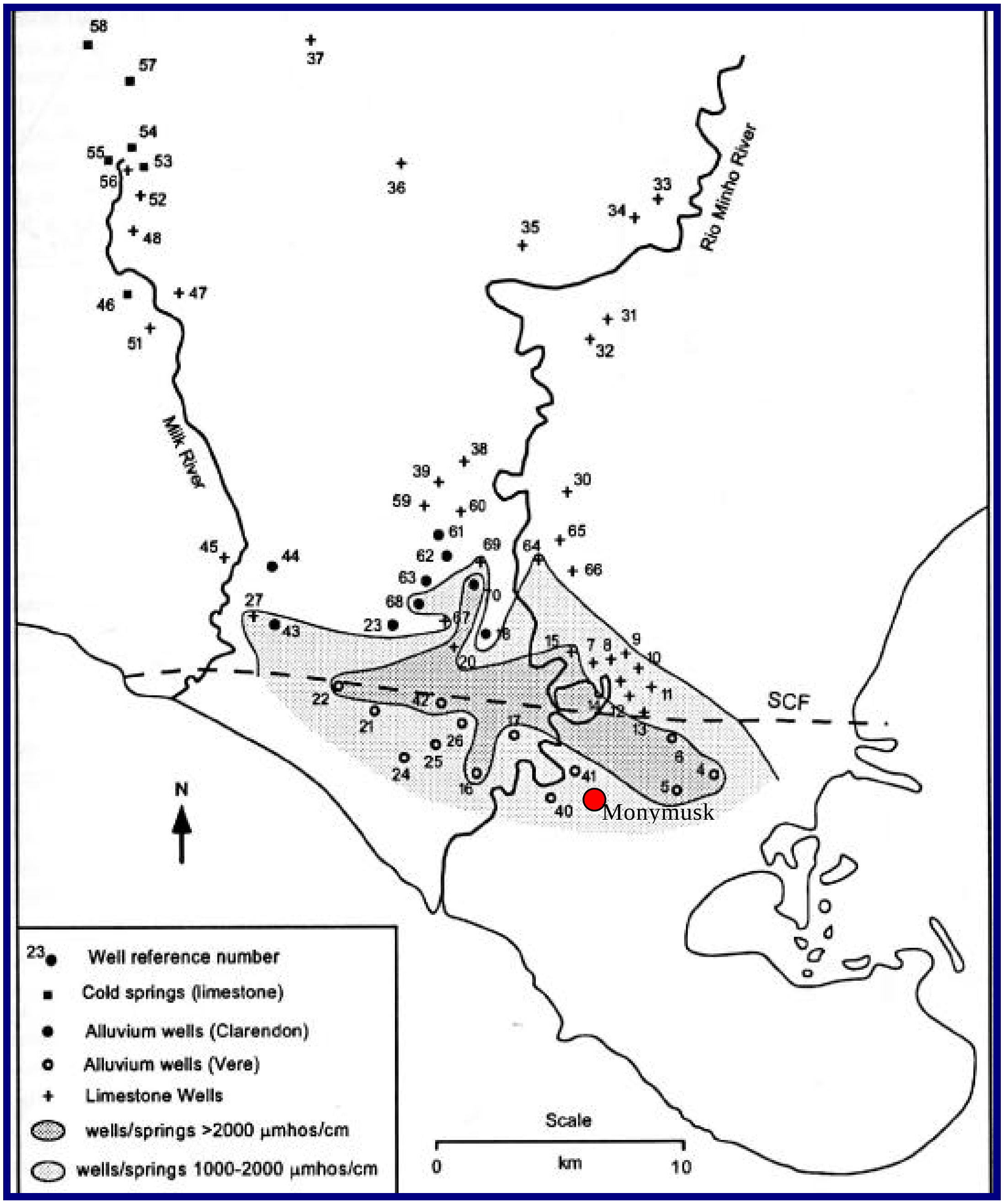


Figure 3.16 Wells affected by salinity in the vicinity of the South Coast Fault, Rio Minho-Milk River basin (Source: Howard and Mullings, 1993).

Rio Minho-Milk River basin.

DISCHARGE

Evapotranspiration

Evapotranspiration has been estimated for both the Rio Cobre and Rio Minho-Milk river basins to be 69 – 70% of the total precipitation in the basins (Appendix I, Table 3). Rather, the net recharge was used which is the total precipitation minus ET and surface runoff i.e. (R_n=P-E_t + R_s.).

Stream Discharge

The two main modes of ground-water discharge from the White Limestone and alluvial aquifers of the Rio Cobre and Rio Minho-Milk river basins are: 1) baseflow to streams and rivers and 2) submarine discharge to the sea. Natural discharge of ground-water to the land surface occurs by way of springs, seepages into streams and rivers surface channels, ponds, or swamps. All of these mechanisms of discharge are lumped as baseflow. Figure 3.17 shows average monthly stream discharges for the Rio Cobre and Rio Minho during 1994 with peaks similar to the mean monthly rainfall distribution patterns over the basin (Figure 1.5). Primary peak flows occur between October and November. Although the shapes of the annual hydrographs of the two streams are very similar, regional differences in stream flow exist. Stream discharge is generally higher in the Rio Cobre basin compared to the Rio Minho-Milk River basin. Variations in stream discharges of the two rivers may be explained in several ways:

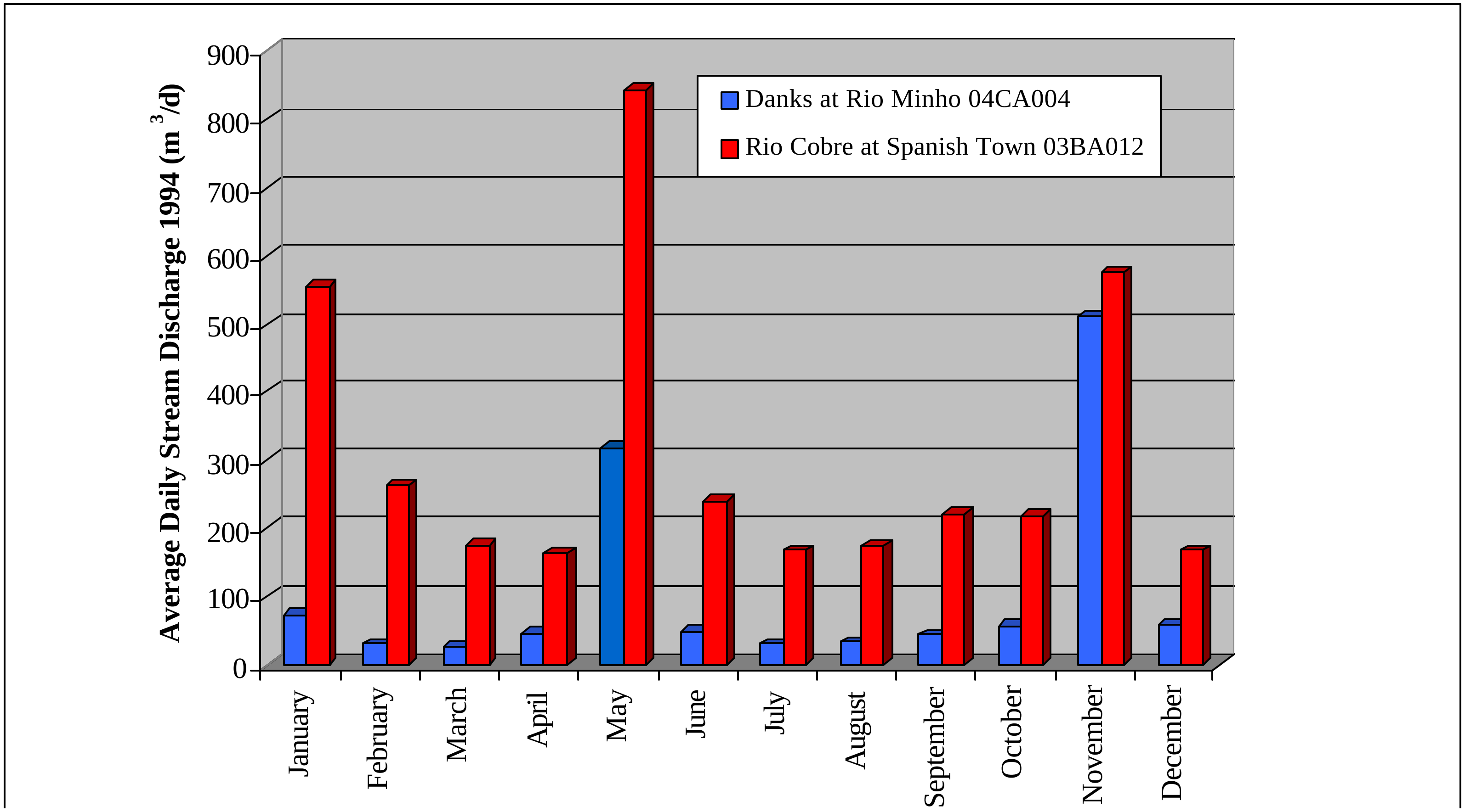


Figure 3.17 Average daily stream discharge (m^3/d) for the upper reaches of the Rio Cobre and Rio Minho-Milk River basin (Source of data: WRAJ, 1998).

1. Flow diversions via conduits from the Rio Minho River results in intermittently reduced flows.
2. The release of water from bank storage in the Rio Cobre after rainfall events results in greater discharges than in the Rio Minho River.
3. Lag times for peak discharge following a rainfall event are lower for the Rio Cobre than for the Rio Minho.

Figure 3.18 shows the locations of the gauging stations where steam discharges were recorded in the Rio Cobre and Rio Minho-Milk river basins.

Baseflow from Cold Mineral Springs

The cold mineral springs are generally coastal with some representing a mixture of intruding seawater and ground-water. Major springs draining the study area are Rio Spring Garden, Ferry, Morgans, Salt Island, and Cockpit Springs. Smaller springs include Whitney River, Piece River, St. Toolis Aligator Hole, Gutt River, and Piece Spring. A river may disappear into a sink and subsequently flow underground. Contact springs develop wherever there are restrictions to flow due to faulting, immature development of the subsurface drainage systems, or they become clogged with clay. Contact springs eventually develop within this area. A number of contact springs (Ford and Williams, 1989) are located along the White Limestone-alluvium boundary and are an indication of a permeable contact exposed at the land surface. Springs are fed from large limestone aquifers and can sustain high flows. Aquifer discharge, which occurs as springflow, often contributes to streamflows and may account for 90 percent of the flow in rivers during

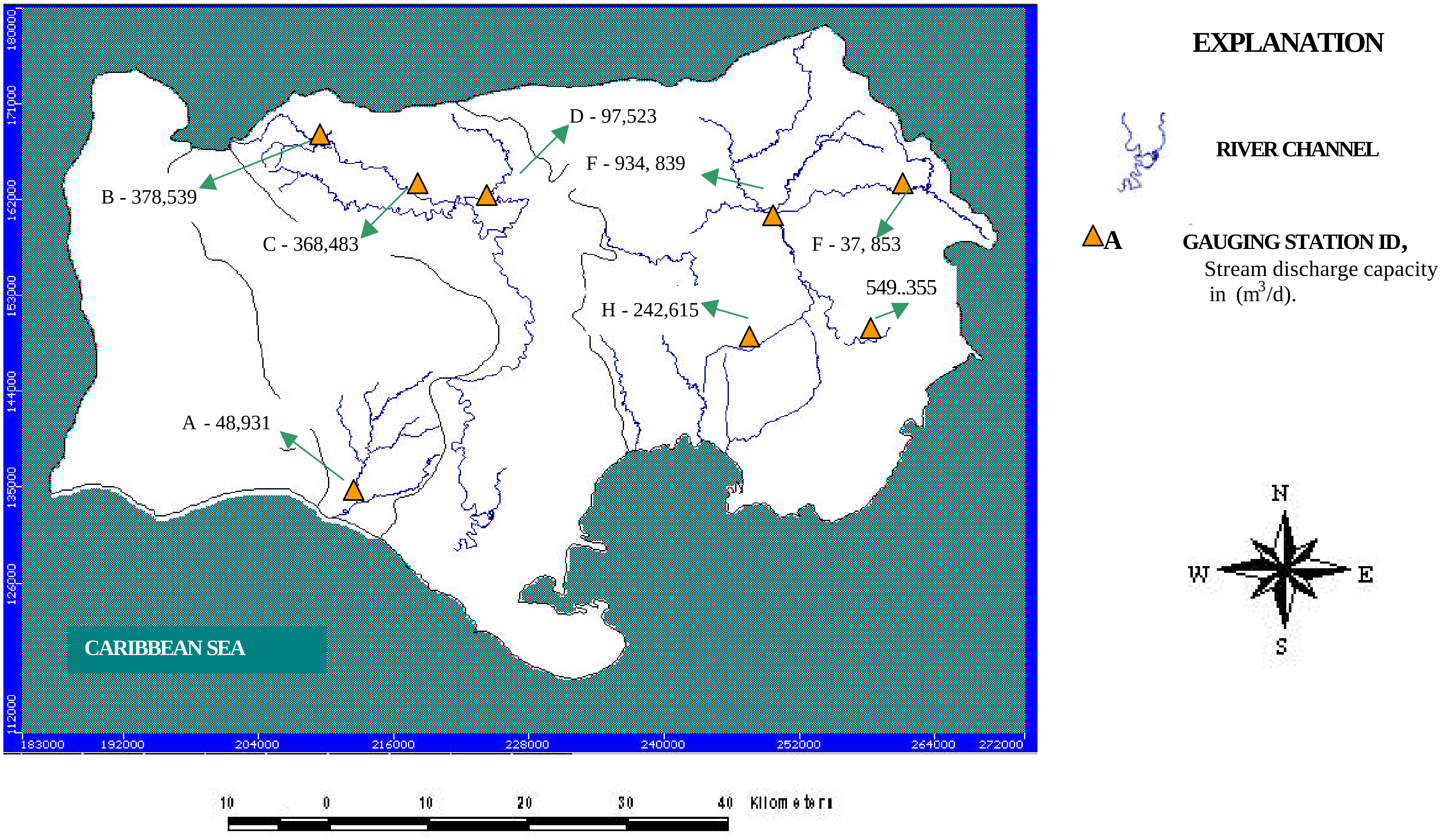


Figure 3.18 Location of gauging stations and stream discharge recorded for the Rio Cobre, Rio Minho and Milk rivers. A – Milk River at Scott's Pass, B – Rio Minho Trout Hall, C – Rio Minho at Danks; D – Pindars River at Rock River; E – Rio Pedro at Harkers Hall; F – Rio Cobre at Bog Walk; G – Rio Cobre at Spanish Town; and H – Rio Cobre Main Canal.

the dry season. Typical discharges recorded for some springs in the Rio Cobre and Rio Minho-Milk river basins are shown in Appendix I: Table 19.

Thermal Springs

The quantity of discharge from thermal springs is small and difficult to measure. It is speculated that these springs are formed by deep circulation of seawater that rises along fissures as a result of convection in the South Coast Fault Zone (Torrence and Chan, 1980). The seawater then becomes heated and mixed with ground-water from the White Limestone aquifer. Two thermal springs are located on Clarendon Block, in close proximity to the South Coast fault: Milk River Spring, situated at the base of Round Hill, and Salt River Spring, at the southern end of the Brazilletto Mountains on the eastern side of the Vere Plains (Figure 3.19). These are warm saline radioactive springs that contain 10,000 – 16,000 curies per liter of Radon^{222} (Vincenz, 1959). Milk River Spring is known as the third most radioactive spring in the world. Vincenz (1959) indicates that the source of dissolved radon in these springs is the Cretaceous and Eocene shales underlying the Eocene limestone or a low-grade economic uranium deposit.

Royall and Banhan (1981) analyzed the total dissolved solids (TDS) of water flowing through four sites located along the Milk River and Salt River (Appendix I, Table 20). They observed similarities between the chemical composition of the water from these springs and the chemical composition of seawater. The composition of the water from the thermal springs includes (1) $CaCl_2$ (1500 ppm), (2) Na_2SO_4 (3,100 ppm), (4) $MgCl_2$ (4,120 ppm), and (5) NaCl (20, 770 ppm).

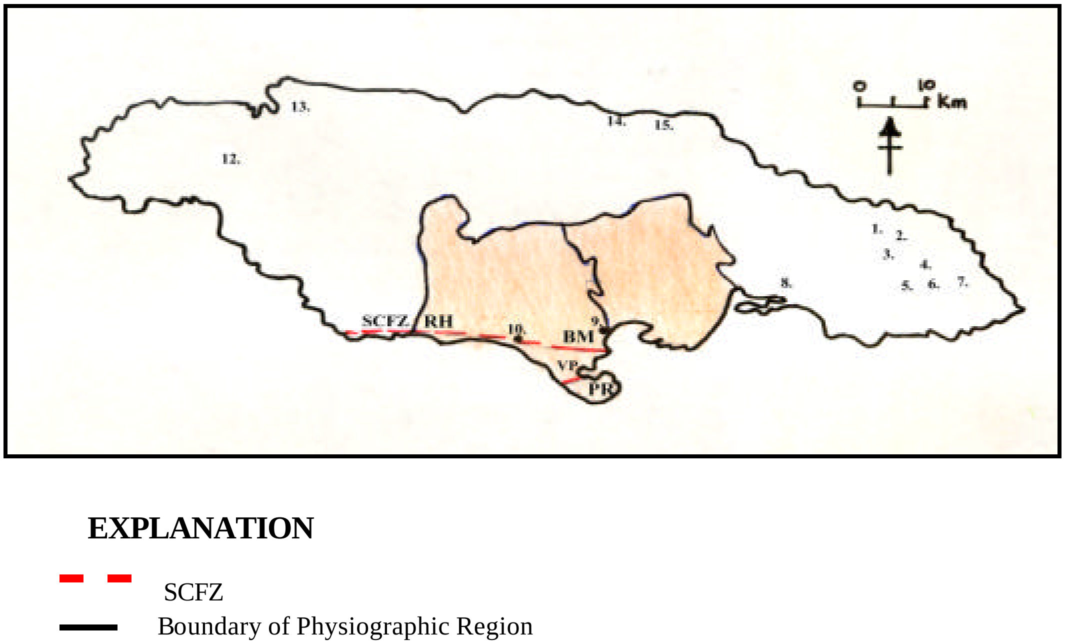


Figure 3.19 Map showing the locations of mineral and thermal springs in Jamaica. (1) Golden Vale Spring, (2) Corn Husk Spring, (3) Guava River Spring, (4) Johnson River Spring, (5) Barband Hall Spring, (6) Banana River Spring, (7) Bath Spring, (8) Rockfort Baths, (9) Salt River Spring, (10) Milk River Spa, (11) Black River Spa, (12) Buxton Spring, (13) Spring Garden, (14) Windsor Spring, (15) Sans Souci Spring, RH – Round Hill, BM – Brazilletto Mountains, PR – Portland Ridge, SCFZ – South Coast Fault Zone, and VP - Vere Plains (Source: Royall and Banhan).