The limestone aquifer is very permeable and of high transmissivity. The Dry River 5R well yielded 8722 m^3/day with a drawdown in the water table of 0.27 metre. The specific capacity, an indication of the wells performance, was 32, 304 m^3/day per metre of drawdown. The transmissivity of the limestone was calculated from the pumping test information as 15,200 m^2/d (15, 200 m^3/day/m).

The high permeability is demonstrated by the loss of circulation (drill water) during the drilling, the drop of the drill string as cavities were encountered and the high yield/low drawdown of the monitor wells when tested using a compressor as a pumping unit. The wells drilled in the vicinity of the REFINERY encountered the water bearing horizons at 13 to 16 metres below sea level. The saturated thickness of the limestone in the area is estimated to be in excess of 150 metres as proven by the Vernamfield well drilled into the same central depression atop which the REFINERY is located. At the final drill depth of the monitor wells there was evidence of high secondary permeability and the saturated thickness was in excess of 110 metres.

The alluvium atop the limestone consists mostly of sands, gravels and clays. The alluvium also fills the fault-incised channels in the underlying limestone. One such channel approximates the course of the Rio Minho. The alluvium thickens southwards from Bowens. The coarser sediments are concentrated within the buried channel and along the course of the Rio Minho. Monitor Well 5 located on the banks of the Rio Minho west of the RDA proved a thickness of 17 metres of coarse sand and gravel with clay between 15 to 17 metres. Examination of the lithologic logs from the monitor wells drilled around the REFINERY indicates a basal layer of clay separating the alluvium from the underlying limestone. The Alcoa No. 1 borehole located at E4655 N3618 encountered 10 metres of white sticky clay atop the limestone. The alluvium in the vicinity of the REFINERY is dry and no water was encountered during the drilling of the monitor wells. The alluvium is unsaturated and functions as an aquiclude (Geomatrix Jamaica Ltd. 1995).

3.3.1.3 STRUCTURE

The area around the REFINERY is a large limestone depression criss-crossed by several faults. The lateral and vertical movements along these faults are responsible for the variation in lithology encountered during the drilling of the monitor and production wells i.e. lower, middle or upper Newport Limestone Formation. Faults that cross the area and trend northeast to southwest and northwest to southeast truncate at the boundary of the alluvium. The faults are buried beneath the alluvium but if extrapolated would meet north of the Webbers Gully at New Bowens settlement. One fault trending northwest to southeast passes east of the bauxite/alumina plant and has incised a deep channel within the limestone. The thickened alluvium encountered in Hanbury No 2R well and Monitor Well 3 mark this fault zone. This fault reappears at Raymonds to the south of Hayes Township where it abuts onto the South Coastal Fault (Figure 3-8).

The UNDP/FAO Water Resources Assessment of the Rio Minho-Milk River Basin, Annex II-Water Resources Appraisal divides the basin into 3 units and treats each unit as being separate. The boundary between Units B and C was said to be a groundwater divide at the western edge of the Brazilletto Mountains until it intersects the South Coastal Fault, which for all purposes is the southern boundary of the limestone aquifer. While there is no evidence for the groundwater divide the fault that is located east of the plant could be the eastern boundary of Unit B.

Cross sections drawn in a north-south and east-west direction across the Halse Hall area show the following:

- The erosional (wavy) surface of the limestone
- The variation in thickness of the alluvium
- The basal clay layer at the limestone/alluvium boundary; and
- The water table in the limestone aquifer.

The cross sections are shown as Figure 3-9 and Figure 3-10

FIGURE 3-9: CROSS-SECTION – EAST-WEST DIRECTION ACROSS THE HALSE HALL AREA

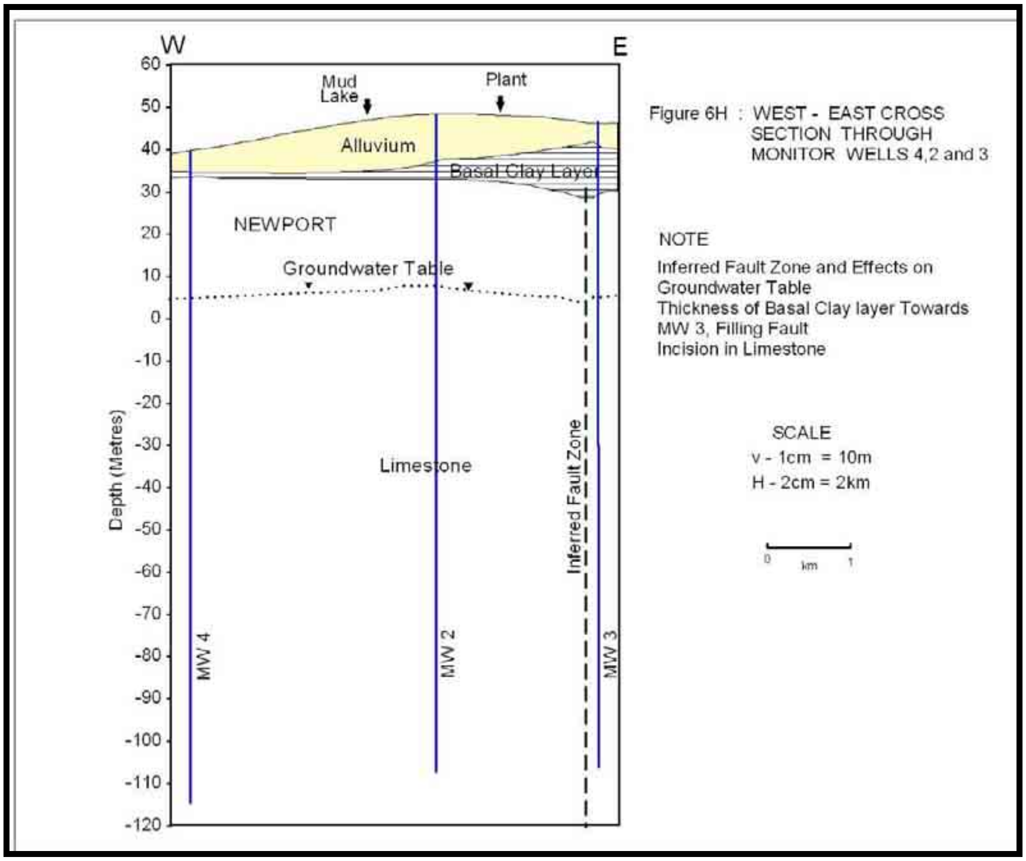
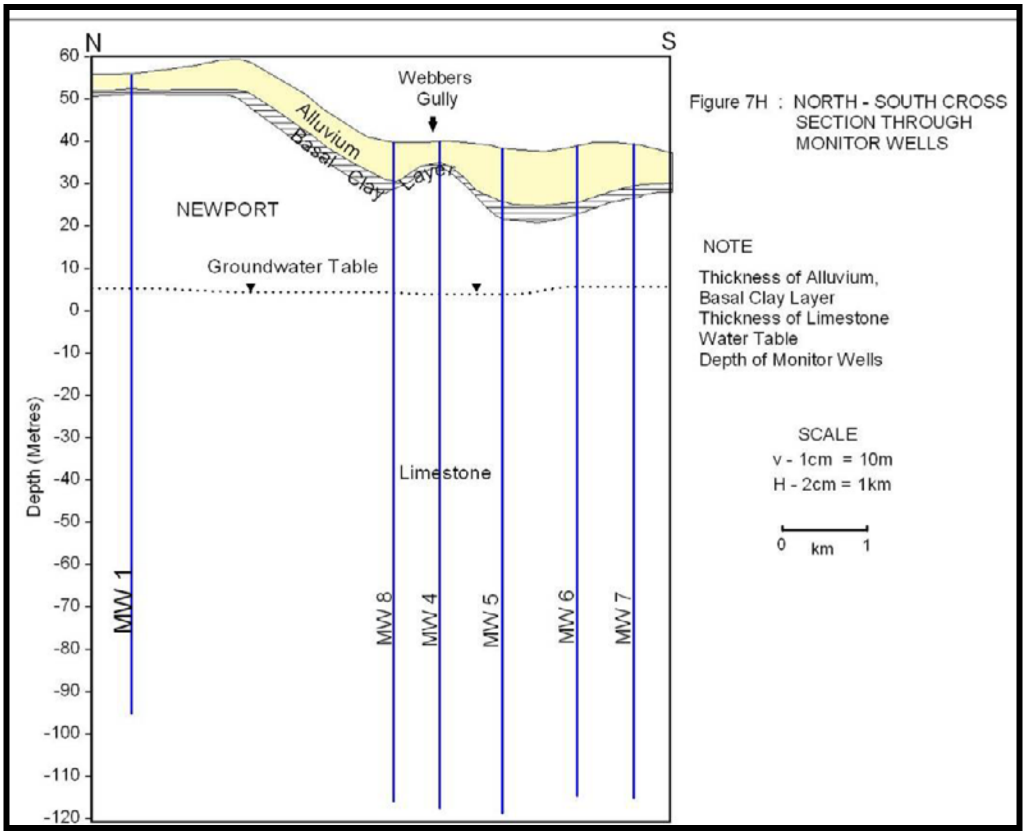


FIGURE 3-10: CROSS-SECTION – NORTH-SOUTH DIRECTION ACROSS THE HALSE HALL AREA



3.3.1.4 TOPOGRAPHY AND DRAINAGE

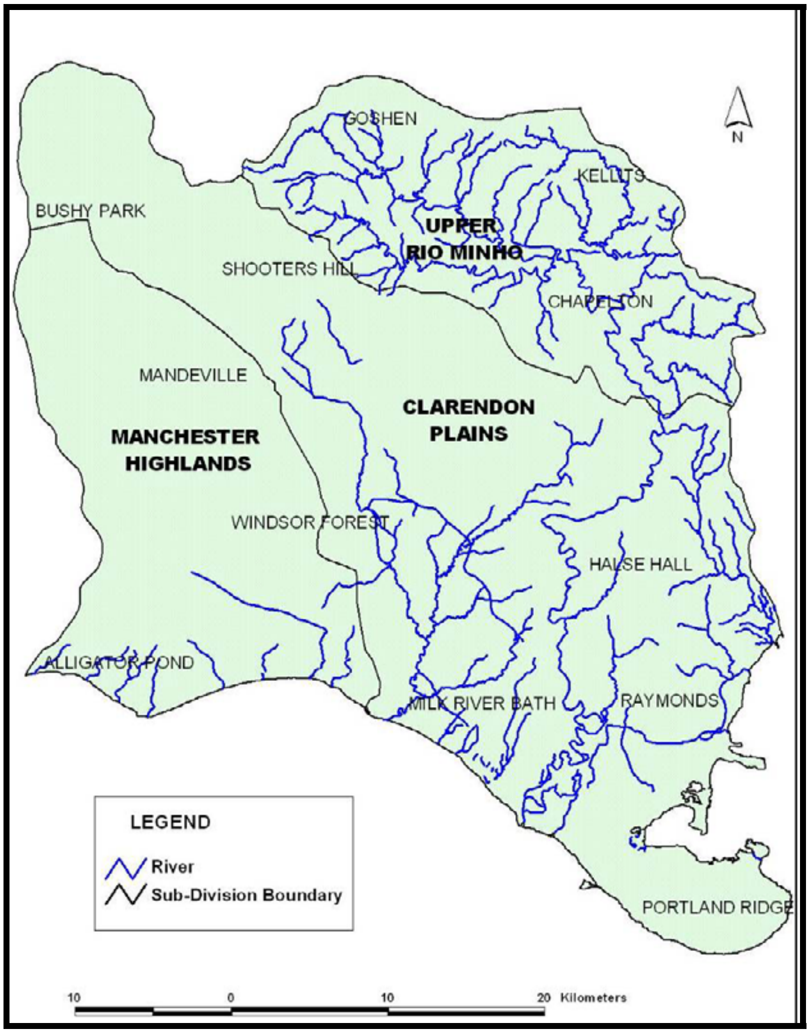
Topographically the area is of low relief with gentle rolling hills on the Harris Savannah. The Brazilletto Mountains form the high ground rising to 250 metres above mean sea level to the east of the bauxite/alumina plant. The Rio Minho flows in a north-south direction west of the RDAs and is the major surface water drainage system. The Webbers Gully, a tributary of the Rio Minho, drains the area north of the Plant. The Webbers Gully is seasonal and carries storm water from the northeast section of the basin into the Rio Minho. During high rainfall events when the Rio Minho is in spate its stage is higher than that of the Webbers Gully with the result that the gully cannot enter the river and will overtop its banks with resultant flooding. The Webbers Gully was straightened to facilitate the construction of the RDA 1 (Mud Lake) and the Clear Lake. The Webbers Gully flows between the northern dike of the RDA 1 and the southern edge of the Clear Lake. Monitor well 8 is located just south of the Webbers Gully before it joins the Rio Minho.

3.3.2 HYDROLOGY

3.3.2.1 SURFACE WATER HYDROLOGY

The hydrologic sub-division of the Rio Minho basin is shown as Figure 3-11.

FIGURE 3-11: Hydrologic Sub-Division of the Rio Minho BASIN



The Rio Minho and the Webbers Gully are the main constituents of the surface water hydrologic system in the Halse Hall area. The Webbers Gully has a sub-basin that covers an area of approximately 17.8km^2.

The Rio Minho, located west of the RDAs, flows in a north-south direction. The Webbers Gully, a tributary of the Rio Minho, drains the area between New Bowens and the plant site. The alluvium filled Webbers Gully joins the Rio Minho Valley through Palmers Cross at the Barrel Hole sink west of Chateau, May Pen. It joins the Rio Minho at Old Bowens flowing north of Monitor well 8.

The Rio Minho and the Webbers Gully are seasonal in flow. The Rio Minho is seasonal between May Pen and Alley. The river loses its flow-an average of 20 million cubic metres per year (MCM/yr) - just north of May Pen to the limestone aquifer. At Alley the river becomes perennial and is sustained by wet season surface water throughflow from the Upper Rio Minho sub-basin (111 MCM/yr) and perennial inflow of irrigation return water (22 MCM/yr), totalling 133 MCM/yr average discharge to the sea. There is no significant contribution to the Rio Minho throughout its passage across the Clarendon Plains sub-basin to the sea.

Ponding of water occurs along the course of both surface water systems. The ponding indicates the effectiveness of the basal clay layer in preventing vertical movement of water through the alluvium to the limestone aquifer. However along the Webbers Gully in the vicinity of the clear lake there are outcroppings of limestone. Surface flow as well as any contaminant can enter the limestone aquifer through these surface exposures of limestone.

3.3.2.2 GROUND WATER HYDROLOGY

Ground water is water that is stored within the saturated section of the limestone formation. The natural level of the water i.e. the water table marks the upper section of this zone of saturation. Rainfall is the sole source of recharge to the ground water system but artificial, intentional or unintentional, inflows can also contribute and may affect ground water type and quality. The impact will depend on several factors and may include.

- Hydrostratigraphy
- Permeability
- Water levels
- Flow direction

As stated above in section 3.3.1.1 the two main hydrostratigraphic units within the project area are the limestone aquifer and the alluvium aquifer/aquiclude. The alluvium is unsaturated and does not function as an aquifer. It can for all purposes be classified as an aquiclude.

A hydrostratigraphic unit is a geologic formation (or series of formations), which demonstrates a distinct hydrologic character. An aquifer is a geologic formation or group of formations that readily and perennially yields water to a spring or well. An aquiclude is the opposite of an aquifer.

The alluvium overlies and confines the limestone aquifer within the project area. The full penetration of the alluvium during the well drilling operations proved its lack of water. The limestone aquifer was partially penetrated to a thickness of 135 metres out of a reported thickness of 1350 metres-10% only. Yet this was the deepest drilling to have been done in the area. The confinement of the aquifer was evident in the drilling of the monitor wells where artesian rises in the water level of up to 14 metres were noted (Geomatrix 1995).

Ground water is ponded within the karstic Clarendon Plains limestone aquifer by clayey alluviums on the downfaulted southern block of the South Coastal Fault. Along its southeastern boundary alluviums and underlying coastal aquicludes act as a barrier to direct outflow to the sea. Note the change (increase) in the elevation of the water table just behind the fault as shown in Figure 3-12.

The alluvium south of the South Coastal Fault is an aquifer and is tapped by the Sugar Company of Jamaica using tube wells to provide irrigation and domestic water to its operations at Monymusk. The thickness of the alluvium in this area was determined in 1978 using a gravity survey (Bouguer Anomaly) to be a maximum of 650 metres (Wadge, Brooks and Royall 1983).

3.3.3 WATER RESOURCES

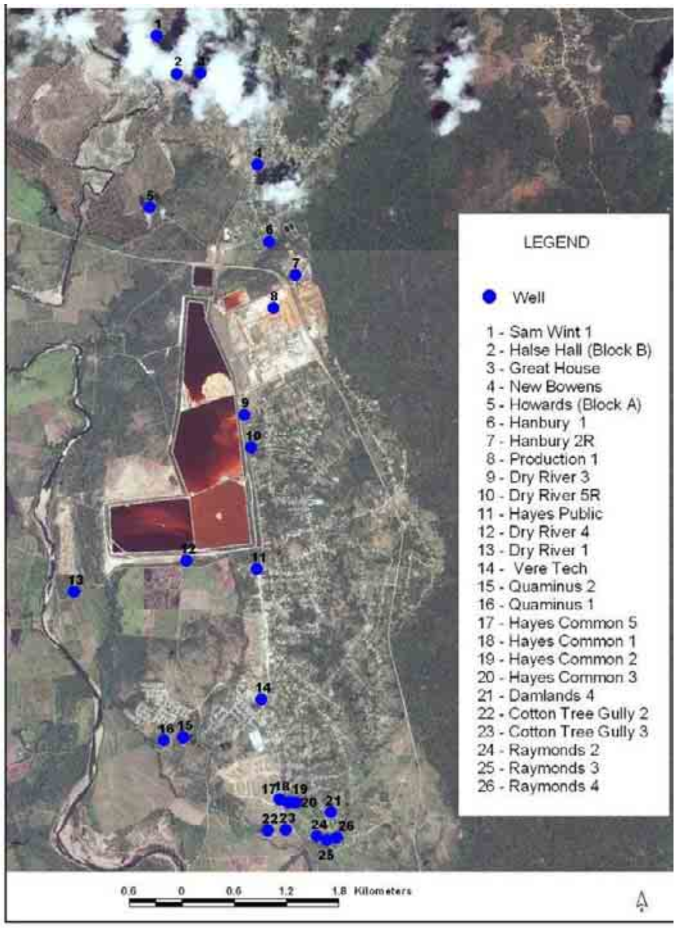
3.3.3.1 WELL LOCATIONS AND YIELDS

There are no hydraulic structures on the Rio Minho River in the vicinity of the proposed site for the development of additional RDAs.

The seasonal character of the main rivers in the Basin combined with the high agricultural demand account for the heavy reliance on ground water. Wells tapping the limestone aquifer produce water for agricultural, domestic and industrial uses. At present over 80% of the water supplied in the basin is from ground water.

There are 26 production wells tapping the limestone aquifer, located east of the Rio Minho River within the Clarendon Plains sub-division and to the north (from Halse Hall Great House) and south (to Raymonds) of the REFINERY. A list of these wells, the owners, their use and licensed/historical yield is given in Table 3-4 below. The locations of these wells are shown in Figure 3-12.

FIGURE 3-12: Location of Production Wells



The greater numbers of the wells is located south of the REFINERY, are all owned by SCOJ, are all used for irrigation and are centered on the Hayes Common-Raymonds area. The location of these wells is along the South Coastal fault that is open to the sea at the western and eastern ends. The high permeability associated with the fault and the ponding of groundwater behind the fault influenced the locations. The wells located along the fault are high producers.

Of these 26 wells the Sugar Company owns 14 that are used for irrigation purposes; the National Water Commission owns 2 for Public Water Supply; the Ministry of Education owns 1 for agricultural uses and Jamalco owns 9 for private domestic, agricultural and industrial uses. The wells owned by Jamalco and used for agricultural purposes are leased to a farming entity.

The total licensed abstraction for the wells owned by Jamalco total 83,830 cubic metres per day (m3/d); that for the National Water Commission totals 10,130 m^3/d; that for the Ministry of Education (Vere Technical well) totals 1,690 m^3/d and the historical abstraction for the Sugar Company of Jamaica (SCoJ) totals 131,112 m^3/d. One well, Quaminus 2, is shared between the NWC and the SCoJ. The NWC purchases water from this well to meet the demands of the Hayes New Town.

The total licensed or historical entitlement of abstraction from the area around the REFINERY is 226,762 m^3/day.

TABLE 3-4: List of Production Wells East of the Rio Minho and within the Vicinity of the REFINERY

Name of Well	Name of Owner	Water Use	Yield (m^3/day)
Great House	Jamalco	Private Domestic	250
Sam Wint	Jamalco	Agriculture	7,560
Halse Hall (Block B)	Jamalco	Agriculture	11,160
Howrads (Block A)	Jamalco	Agriculture	10,880
Dry River 3	Jamalco	Industrial	9,815
Dry River 5R	Jamalco	Industrial	9,815
Hanbury 1	Jamalco	Industrial	8,184
Hanbury 2R	Jamalco	Industrial	10,902
Production 1	Jamalco	Industrial	15,264
New Bowens	National water Commission	Public Supply	3,272
Hayes Public	National water Commission	Public Supply	6,858
Vere Technical	Ministry of Education	Agricultural/Domestic	1,690
Hayes Common 1	Sugar Company of Jamaica	Irrigation	11,088
Hayes Common 2	Sugar Company of Jamaica	Irrigation	13,944
Hayes Common 3	Sugar Company of Jamaica	Irrigation	10,224
Hayes Common 5	Sugar Company of Jamaica	Irrigation	11,088
Quaminus 1	Sugar Company of Jamaica	Irrigation	15,936
Quaminus 2*	Sugar Company of Jamaica	Irrigation	8,184
Cotton Tree Gully 2	Sugar Company of Jamaica	Irrigation	9,168
Cotton Tree Gully 3	Sugar Company of Jamaica	Irrigation	9,096

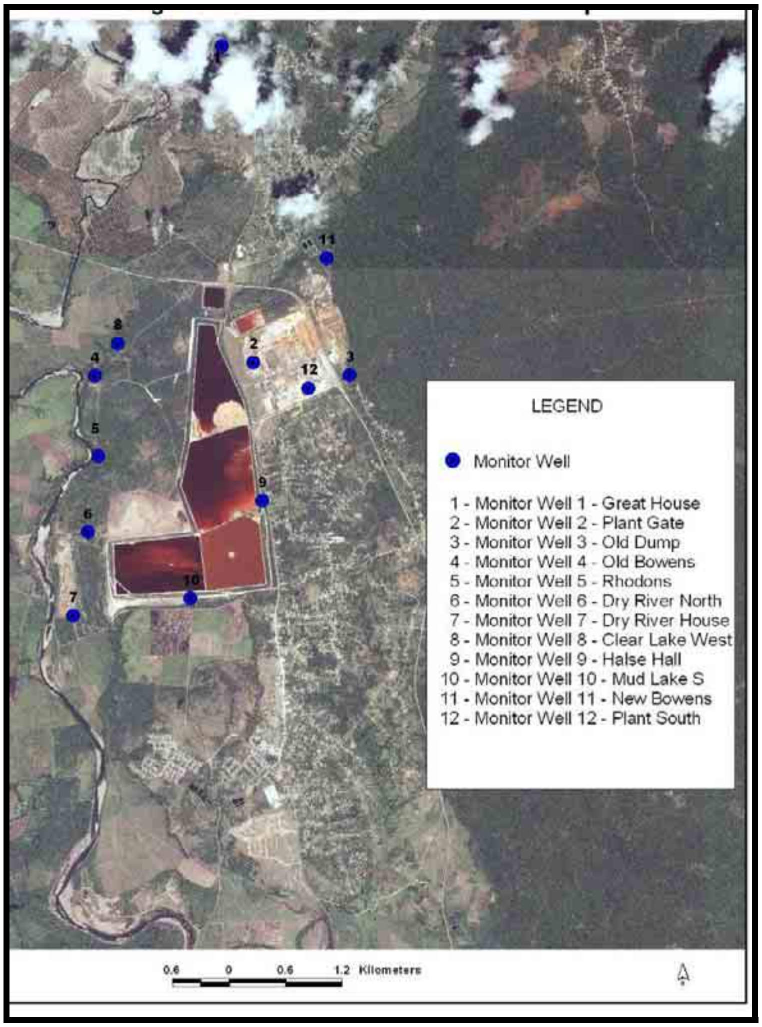
Name of Well	Name of Owner	Water Use	Yield (m^3/day)
Damlands 4	Sugar Company of Jamaica	Irrigation	2,760
Raymonds 2	Sugar Company of Jamaica	Irrigation	6,072
Raymonds 3	Sugar Company of Jamaica	Irrigation	9,168
Raymonds 4	Sugar Company of Jamaica	Irrigation	10,200
Dry River 1	Sugar Company of Jamaica	Irrigation	9,168
Dry River 4	Sugar Company of Jamaica	Irrigation	5,016

*- well shared between SCoJ and NWC.

In addition to the 26 production wells there are two disused production wells, Dry River 2 and Dry River 6, as well as twelve (12) monitor wells located around the REFINERY. Of the 12 monitor wells one has been destroyed (Monitor Well 7) and one has become inaccessible due to expansion of the plant.

The 12 monitor wells were drilled in 2 phases. Phase 1 saw 8 wells being completed in 1994 with a further 4 wells in phase 2 being completed in 1997. The locations of the monitor wells are shown as Figure 3-13.

FIGURE 3-13: Location of the Monitor Wells



<u>TABLE 3-5: Construction Details of Monitor wells-Jamalco-REFINERY (MS-MEDIUM SAND FS-FINE SAND)</u>

Monitor Well		Drill Hole		Casing/Screen					Filter Pack				Seal	Cement Grout
No.	Name	Dia. (cm)	Depth (m)	Type	Dia. (cm)	From (m)	To (m)	Length (m)	Type	From (m)	To (m)	Thickness (m)		
1	Great House	10.16	152.4	Blank	5	+0.3	146.3	146.6	MS	-1.5	141.7	140.2	141.7	1.5 0 to 1.5
				Screen	5	146.3	149.3	3.0	FS	141.7	143.2	1.5		
				Bank	5	149.3	152.4	3.1	MS	143.2	152.4	9.2		
2	Plant Gate	10.16	155.4	Blank	5	+0.3	149.3	149.6	MS	-1.5	141.7	140.2	141.7	1.5 0 to 1.5
				Screen	5	149.3	152.4	3.1	FS	140.2	143.2	3.0		
				Bank	5	152.4	155.4	3.0	MS	143.2	155.4	12.2		
3	Old Dump	10.16	155.4	Blank	5	+0.3	149.3	149.6	MS	-1.5	144.8	143.3	144.8	1.5 0 to 1.5
				Screen	5	149.3	152.4	3.1	FS	144.8	146.3	1.5		
				Bank	5	152.4	155.4	3.0	MS	146.3	155.4	9.1		
4	Old Bowens	10.16	155.4	Blank	5	+0.3	149.3	149.6	MS	-1.5	144.8	143.3	144.8	1.5 0 to 1.5
				Screen	5	149.3	152.4	3.1	FS	144.8	146.3	1.5		
				Bank	5	152.4	155.4	3.0	MS	146.3	155.4	9.1		
5	Rhodons	10.16	155.4	Blank	5	+0.3	149.3	149.6	MS	-1.5	144.8	143.3	144.8	1.5 0 to 1.5
				Screen	5	149.3	152.4	3.1	FS	144.8	146.3	1.5		
				Bank	5	152.4	155.4	3.0	MS	146.3	155.4	9.1		
6	Dry River North	10.16	152.4	Blank	5	+0.3	146.3	146.6	MS	-1.5	143.3	141.8	143.3	1.5 0 to 1.5
				Screen	5	146.3	149.3	3.0	FS	143.3	144.8	1.5		
				Bank	5	149.3	152.4	3.1	MS	144.8	152.4	7.6		
7	Dry River House	10.16	155.4	Blank	5	+0.3	149.3	149.6	MS	-1.5	143.3	143.3	143.3	1.5 0 to 1.5
				Screen	5	149.3	152.4	3.1	FS	143.3	148.8	1.5		
				Bank	5	152.4	155.4	3.0	MS	144.8	155.4	10.6		
8	Clear Lake West	10.16	155.4	Blank	5	+0.3	149.3	149.6	MS	-1.5	143.3	141.8	143.3	1.5 0 to 1.5
				Screen	5	149.3	152.4	3.1	FS	143.3	146.3	3.0		
				Bank	5	152.4	155.4	3.0	MS	146.3	155.4	9.1		
9	Halse Hall	10.16	155.4	Blank	5	+0.6	128.0	128.6	MS	-1.5	127.5	126.0	126.5	1.5 0 to 1.5
				Screen	5	128.0	131.0	3.0	FS	127.5	134.0	6.9		
				Bank	5	131.0	134.0	3.0	MS	134.0	155.4	21.0		

Monitor Well		Drill Hole		Casing/Screen					Filter Pack				Seal	Cement Grout
No.	Name	Dia. (cm)	Depth (m)	Type	Dia. (cm)	From (m)	To (m)	Length (m)	Type	From (m)	To (m)	Thickness (m)		
10	Mud Lake South	10.16	155.4	Blank Screen Bank	5 5 5	+0.8 146.3 149.3	146.3 149.3 152.3	147.1 3.0 3.0	MS FS MS	-1.5 140.0 152.4	140.0 152.4 155.4	138.5 12.4 3.0	140.0	1.5 0 to 1.5
11	New Bowens	10.16	155.4	Blank Screen Bank	5 5 5	+0.8 149.4 152.4	149.4 152.4 155.4	150.2 3.0 3.0	MS FS MS	-1.5 122.0 154.0	122.0 154.0 155.4	120.5 32.0 1.4	121.5	1.5 0 to 1.5
12	Plant Site South	10.16	152.4	Blank Screen Bank	5 5 5	+0.4 137.2 140.2	137.2 140.2 143.2	137.6 3.0 3.0	MS FS MS	-1.5 91.5 143.2	91.5 143.2 155.4	90.0 51.7 12.2	90	1.5 0 to 1.5

Each well was drilled to a depth of 155.4 metres and completed with 5 cm diameter PVC casing and screen. The annular space of each well was packed with gravel and coarse sand. The screened area, which was close to the bottom of the well, was packed off using bentonite as a seal. Development was carried out using a compressor as the pumping unit. Water samples were collected every 30 metres to develop a water quality profile with depth. The locations of the monitor wells are shown on Figure 3-10

Details on the construction of the monitor wells are given in Table 3-5 above.

3.3.3.2 GROUNDWATER LEVELS

Groundwater level (elevation of water table above sea level) is monitored monthly by Jamalco staff at each of the 10 accessible monitor wells. The groundwater table fluctuates seasonally with recharge and abstraction/discharge. When recharge exceeds abstraction/recharge the storage increases and the water table rises. When abstraction/discharge exceeds recharge water is taken from storage and the water table elevation will decline. In the dry season the water table elevation in the area around the REFINERY varies from 2.40 to 4.10 metres above sea level with the highest level being recorded at Monitor Well 1 to the north.

The year 2003 was one of high water table elevations as the recharge from the extreme rainfall events in May/June and September of 2002 increased storage within the limestone aquifer. Water table elevations around the REFINERY remained higher than 6 metres above sea level for all of 2003. In fact at two wells, monitor wells 1 and 12, the water table elevation was higher than 7 metres above sea level. This has gradually declined and in April of 2004 the water table elevations varied from a high of 5.34 (in the north of the area) to a low of 4.51 (west of the RDAs) metres above sea level. There has not been a decline in the groundwater table since the measurements began in 1998.

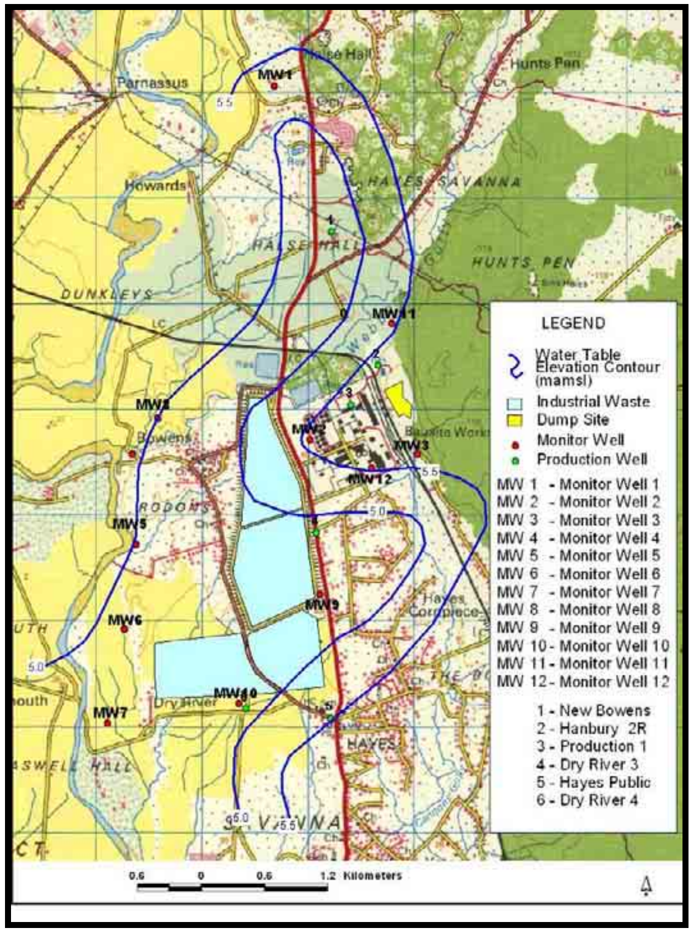
The water table elevation upon completion of the monitor wells and that on April 1, 2004 is compared in Table 10 below.

Table 3-6: COMPARISON OF WATER TABLE ELEVATIONS FOR THE MONITOR WELLS

Name of Well	Water Table Elevation (M asl)		Remarks
	Upon Completion	April 2004	
Monitor Well 1	3.35	5.20	MW 1-8 completed
Monitor Well 2	4.63	5.63	In 1994
Monitor Well 3	4.23	5.23	
Monitor Well 4	4.37	4.95	
Monitor Well 5	3.85	4.97	
Monitor Well 6	3.79	4.51	
Monitor Well 8	3.84	4.97	
Monitor Well 9	3.91	4.80	MW 9-12 completed
Monitor Well 10	3.87	4.81	In 1997
Monitor Well 11	3.79	5.34	
Monitor Well 12	3.87	7.38*	*June 2004

The water table elevation map for April 2004 is shown as Figure 3-14. The groundwater table elevation shows a high of just over 6 metres above sea level. The direction of flow is from the high to the low elevation and is from north to south through the REFINERY.

FIGURE 3-14: Water Table Elevation Map



3.3.3.2.1 DISCHARGE

Knowledge of the discharge to the sea via the limestone south of the South Coastal Fault is not known. There is no evidence to show that there is a discharge along this reach to the sea. The actual discharge into the sea may be some distance offshore where the White Limestone is exposed to the seabed. It is possible that outflow may be restricted to those periods of high water table and marine discharge in normal conditions may be small.

The principal discharge from the aquifer is by abstraction from pumped wells. In Table 3-4 a list of the pumped wells is given with the licensed or historical abstraction rates.

The total committed water for abstraction from the area around the REFINERY was 226,762 m^3/day (10.30 x 108 imperial gallons per day). There has never been a period when all the wells have been abstracting at their maximum and the 226,762 m3/day was being abstracted. This area of the limestone aquifer has the greatest abstraction in the basin and is concentrated in particular to the area south of the REFINERY that includes the Hayes Common-Raymonds area. Many of the wells suffer from saltwater contamination either from penetration of the fresh water-seawater interface along the South Coastal Fault, the movement of saltwater (influenced by the pumping) along the fault that is open to the sea at both the western and eastern ends or the recirculation of return saline irrigation water.

3.3.3.2.2 RESERVOIR VOLUME

The effective ness of an aquifer to supply water on a reliable basis is determined by the volume of the reservoir rock capable of holding the water. The effective volume of the reservoir is that amount of water that the rock will yield.

The thickness of the permeable section of the aquifer in the northern area of the basin is not known. However this is determined by the depth to the impermeable basement rocks (Yellow Limestone or Volcanic rocks) and the aquifer is thin where these rocks are near to the surface. In the area around the REFINERY the impermeable sediments are covered by the great thickness of the White Limestone (Newport Formation) and they do not affect the depth to which water can penetrate. The depth of solution in the limestone is limited by the lowest base level in effect during the history of solution development. The degree of karstification has a direct bearing on the capacity of the limestone to store and transport water. In the area beneath the REFINERY the level of karstification and high permeability in the limestone was found to be over 100 metres deep and has been proven to be over 150 metres deep within the central depression.

The reservoir volume is assumed to be equivalent to the saturated thickness of the reservoir. Assuming a saturated thickness of at least 100 metres and an area of the aquifer bounded by the South Coastal Fault to the south, by the Rio Minho to the west, by the fault between the plant and the Brazilletto Mountains to the east and by an imaginary east-west line drawn north of the Great House and Sam Wint wells with an approximate area of 34.5 square kilometres, the volume of the reservoir would be 345 million cubic metres of water (a value of 10% is used for the calculation of the reservoir volume).

The groundwater table elevations are relatively flat in the central area of the basin and around the REFINERY. They are controlled by several factors, which will include the storativity and the transmissivity of the aquifer. The dry season water table elevation varies from 2.5 metres above sea level to a high of 5 metres above sea level, which gives an average water table elevation of approximately 3.75 metres above sea level within the study area. The total water that could be abstracted is 12.94 MCM.

3.3.4 WATER QUALITY

3.3.4.1 AMBIENT WATER QUALITY

The groundwater resources of the Clarendon Plains and the area around the REFINERY are associated with the limestone aquifer, which occurs throughout the area and fills the central depression. Except where contaminated by industrial and municipal effluents or seawater, the quality of the groundwater is adequate for all standard uses. Physical, chemical and bacteriological quality is generally as follows:

- pH 7.2
- Conductivity 450 to 700 uS
- TDS 250 to 450 mg/l
- Coliform 5 MPN/100 ml.

Total Dissolved Solids (TDS) tends to be slightly high for use in industrial boilers without softening, but the bacteriological quality requires minimum treatment for use as a municipal/ public or private water supply. However where contamination has occurred the quality would vary depending on the nature of the contaminant.

The typical background quality of the groundwater in the limestone aquifer is shown in Table 3-7 below.

TABLE 3-7: TYPICAL BACKGROUND QUALITY OF GROUNDWATER IN THE LIMESTONE AQUIFER-CLARENDON

Constituents	Units	Concentrations
pH		7.2
Turbidity	NTU	<1.0
Colour	HU	<5
Specific Conductivity	uS	550
Calcium	mg/l	<75

Constituents	Units	Concentrations
Magnesium	mg/l	10
Sodium	mg/l	12
Potassium	mg/l	1.0
Iron	mg/l	0.01
Chloride	mg/l	10
Sulphate	mg/l	8
Nitrate	mg/l	4
Carbonate	mg/l	0.0
Bicarbonate	mg/l	260
Total Hardness	mg/l	270
Total Alkalinity	mg/l	260
Total Dissolved Solids	mg/l	350
Bacteriological	MPN/100 ml	<5
Na:Cl ratio		<1.5

3.3.4.2 GROUNDWATER CHEMICAL TYPES

All groundwater can be classified into types according to the dominance of various anions and cations in the water. The major types are:

1 Calcium/Magnesium bicarbonate
2 Sodium bicarbonate
3 Calcium chloride
4 Sodium chloride

Natural groundwater, which is uncontaminated, has as the dominant cation, calcium or magnesium, dependent on the source rock through and over which the water flows. The dominant anion is bicarbonate and together with the dominant cation, the chemical water type becomes calcium or magnesium bicarbonate water. The changes from the naturally occurring calcium bicarbonate type water to the sodium chloride type water is an indication of contamination of the groundwater and the replacement of the calcium by sodium and the bicarbonate by chloride.

Around the REFINERY the major groundwater chemical type is the calcium bicarbonate type with sodium chloride type to the south around Hayes Common-Raymonds and at depth within the limestone aquifer.

3.3.4.3 Sources of Groundwater Contamination

The assessment of any change in groundwater quality and type must include an evaluation of the possible sources of contamination and the impact each can have on water quality.

Around the REFINERY there are three main possible sources of contamination of groundwater. These are:

1 The intrusion of saltwater (saline intrusion) into the karstic aquifer as a result of the **over pumping** resulting in high chloride and sodium concentrations.

2 **Industrialization**, specifically the bauxite/alumina operations at Halse Hall consisting of the plant and the RDAs.

3 **Municipal** impacts from the improper disposal of liquid and solid wastes.

3.3.4.3.1 Saltwater Intrusion

The limestone formation responds as a Ghyben-Herzberg aquifer. The Ghyben-Herzberg Principle specifies that the occurrence of saline groundwater in a coastal aquifer, similar to that of the Rio Minho Hydrologic basin within which the REFINERY is located, is dependent on the head of fresh water above sea level. A ratio if 1:40 i.e. one metre of fresh groundwater above sea level to 40 metres of fresh groundwater below sea level before entering the freshwater/saline water interface. This has been proven by Botbol in the adjoining Rio Cobre Hydrologic basin a karstic limestone area. Around the REFINERY with water levels 6 metres above sea level there should be 240 metres of freshwater below sea level before the fresh/salt water interface is encountered.

Within the area of the REFINERY the potential for saline intrusion by way of upconing from the Ghyben–Herzberg Zone is provided by the below sea level pumping depressions associated with the well fields around the Hayes Common-Raymonds area. The saline water can also be brought to the upper level of the aquifer by way of the faults, which act as preferred paths of flow due to the increased permeability along the fault zones. In addition the wells south of the REFINERY are all located along the South Coastal Fault Zone, which is open to the sea at both its eastern and western ends.

3.3.4.3.2 INDUSTRIALIZATION-BAUXITE/ALUMINA OPERATIONS

The bauxite/alumina industry produces an alkaline waste known commonly as “red mud”. This bauxite residue is a thick fluid suspension with water content between 65 – 75% depending on the technology and method of management used, high concentrations of sodium and hydroxide ions; iron oxides and organic substances which originate from the bauxite and which on decomposition and reaction with caustic soda, impart an unpleasant smell to the water. The pollutants present in the bauxite residue are in sufficient quantities to make the groundwater unfit for domestic and agricultural uses, in the event the bauxite residue is not effectively contained within the storage areas. Effective containment is achieved through the use of sealants such as clay.

The REFINERY was constructed in the early 1970’s. The plant is located on the Clarendon Plains an important agricultural region where over 90% of the irrigation water and 100% of the public water supply is derived from groundwater using wells tapping the limestone aquifer. The bauxite residue is a potential agent for degrading this water quality with potentially significant social and economic consequences.

The bauxite residue is disposed of into Residue Disposal Areas (RDA). RDA 1 was commissioned into use on March 6, 1972. RDA 2 and RDA 3 were constructed in 1980 and 1990 respectively. RDA 4 was constructed in 2000 and the dike was raised by an additional 20 feet in 2004. The RDAs have all been sealed with clay in the base and the sides. Supernatant (caustic enriched) liquor and plant runoff are collected and stored in RDAs (clear and storm lakes) from where it is recycled into the plant. Total volume of mud in storage exceeds 15 million tonnes.

3.3.4.4 CONTAMINATION CRITERIA

The monitoring programmes established by Jamalco in conjunction with the Government of Jamaica regulating agencies are intended to detect above average concentrations of the chemical constituents that can contaminate the groundwater. The inclusion of the aesthetic indices such as colour, taste and odour also assist in the determination of the level of contamination of groundwater.

Five indices are specifically used to detect contamination from the bauxite/alumina operations. These are:

Sodium to chloride concentration ratio exceeding the maximum ratio encountered in uncontaminated groundwater in Jamaica of 1.5 (White and Rose 1975).

1 High sodium content. This alone is not a precise indicator as sodium chloride waters are found in the limestone aquifer as a result of saline intrusion. However in this form of contamination high sodium concentrations are associated with high chloride concentrations. This is not the case in the event of a caustic contamination.

2 Sodium to calcium concentration ratio in excess of the ratios generally encountered in uncontaminated groundwater of 1.0

3 High pH values in excess of 8.5 units, the limit set by the USEPA and the WHO for drinking water and the maximum encountered in groundwater in Jamaica.

4 The presence of suspended solids, red discoloration, poor smell and unpleasant taste.

In addition high conductivity, TDS and alkalinity concentrations aree used to determine the source of the contamination.

3.3.4.4.1 WATER QUALITY MONITORING

Jamalco has conducted water quality monitoring around the REFINERY since 1989. The programmes have been intensified over the years to generate information on the impact of the bauxite/alumina operations on the groundwater quality of the limestone aquifer. Initially the programme consisted of monthly sampling and analysis of existing production wells within and around the REFINERY. The drilling of the monitoring wells has led to the expansion of the monitoring programmes and the level of the analysis done. The monitoring and analysis has led to an increased database on which to base the evaluation of the impacts of the bauxite/alumina operations on groundwater quality. To date the following have been completed and for which data is available:

1 Analysis on a monthly basis of production wells between January 1998 to the present for the parameters- pH, conductivity, chloride, sulphate, sodium, magnesium carbonate, calcium carbonate, and hardness. The sodium:chloride

ratio was calculated from the results. The sampling points included-Production wells 1 and 2, Hayes Common wells 1,2 and 3, Dry River 2 and 5 wells, Hayes Public well, Quaminus 2 well, Halse Hall well (Greenvale), Woodside well, Breadnut Valley well, Rocky Point (Morelands) well, Rocky Point drinking water (trucked water) and Webbers Gully.

2 The completion of the first 8 monitor wells in 1994 led to the expansion of the programme and provided monitor points that were not affected by pumping and tapped groundwater deep within the aquifer.

3 The completion of the next 4 monitor wells in 1997 further expanded the programme.

4 During the drilling of the monitor wells water samples were collected every 30 metres depth below the water table to ensure that a water quality profile of the monitor well could be developed. Each monitor well yielded 4 sets of samples. The parameters analyzed are shown in Table 3-8 below.

5 Since 1998 Jamalco has contracted a consultant to carry out quarterly sampling and analysis of all the wells as an independent assessment of the impacts of the bauxite/alumina operations on water quality. The samples are analyzed by a USEPA and NELAP certified laboratory in the USA. The sample points and the parameters analyzed are shown in Table 3-9. Jamalco at the same time continues its independent sampling and analysis of the same monitor points.

6 In 2000 Jamalco instituted a twice-yearly sampling of all the sources of water to its facilities to assess the quality of water being used for domestic purposes. The sampling points and the parameters analyzed are shown in TABLE 3-10 below.

The data collected has been analyzed and to date no significant contamination of groundwater has been detected.

TABLE 3-8: Parameters Analyzed for each Water Sample, MW1 to 12.

Group of Parameters	Constituents
Metals	Aluminium: Arsenic: Barium: Cadmium: Calcium: Chromium: Iron: Lead: Magnesium: Manganese: Mercury: Selenium: Silver: Sodium.
Inorganics	Cyanide (Total): Chloride: Carbonates: Bicarbonates: Nitrate: Sulphate: Hexavalent Chromium.
Physical/chemical	Turbidity: pH: Specific Conductance
Organics	Phenol: Polychlorinated Biphenyls (PCB): Naphthalene
VOAs (Volatile Organic Aromatic Compounds)	Acetone: Benzene: toluene: Carbon Tetrachloride: Vinyl Chloride: Chloroform: Chlorobenzene: 1,1-Dichloroethane: Methyl Ethyl Ketone (2-Butane)
TPH (Total Petroleum Hydrocarbons)	Hydrocarbons-Petroleum

TABLE 3-9: List of Wells and Parameters-Monthly Sampling Programme Jamalco

Sampling Point	Well Depth (m)	Use of Water	Parameters
Monitor Well 1	155.4	Monitoring	Lab:- Sodium
Monitor Well 2	155.4	Monitoring	Calcium,
Monitor Well 3	155.4	Monitoring	Magnesium
Monitor Well 4	155.4	Monitoring	Chloride
Monitor Well 5	155.4	Monitoring	Sulphate
Monitor Well 6	155.4	Monitoring	Nitrate
Monitor Well 8	155.4	Monitoring	TDS
Monitor Well 9	135.0	Monitoring	Alkalinity
Monitor Well 10	152.4	Monitoring	
Monitor Well 11	155.4	Monitoring	Field:- pH
New Bowens	70.1	Public Supply	Temp.
Dry River 3	76.2	Industrial	Cond.
Dry River 4	55.8	Irrigation	
Hayes Public	67.0	Public Supply	Water Levels
Production 1	86.3	Industrial	Na:Cl ratio
Production 2	122.0	Industrial	calculated

Duplicate samples are collected and a comparison made of the analytical results between the Jamalco Laboratory and the USEPA Laboratory in the USA that analyses the samples. The comparison indicates that on the whole the results compare favourably. However at times the difference in the chloride concentration has been very large. This probably due to the fact that the samples are analyzed beyond the maximum holding time and the samples were not preserved in the field.

TABLE 3-10: LIST OF FACILITIES, SOURCES, SAMPLE SITES AND PARAMETERS ANALYZED

Facility/Location	Source/Supply	Sample Site	Parameters
Clarendon Alumina Works [REFINERY]	Production Well 1	At Well Head	**Metals:** Aluminium; Arsenic: Cadmium: Calcium: Copper: Iron: Lead: Magnesium; Manganese: Mercury: Selenium: Sodium: Zinc **Non-metals:** Chloride; Cyanide: Fluoride; Nitrate: Sulphate: TDS: pH; Temp.: **Bacteria:** Coliform -T and F **Pesticides:** gamma-BHC: Aldrin: Dieldrin: 4,4'-DDT: Technical Chlordane: Methoxychlor. **Organics:** 1,1-Dichloroethane: Chloroform: Benzene: 1,2-Dichloroethane: 2,4,6-Trichlorophenol: Pentachlorophenol: Hexachloroethane: Benzo(a)Pyrene.
	Production Well 2	At Well Head	
	Dry River Well 3	At Well Head	
	Groundwater from PW 1/PW 2 after Treatment	Drinking Fountain in Building 1	
Halse Hall Great House	Great House Well	At Well Head	
	Great House Well after Treatment	At Great House Kitchen Tap	
Breadnut Valley	Breadnut Valley Well	At Well Head	
	Breadnut Valley Well after Treatment	Drinking Fountain in Plant Office	
Woodside Lands Office	NWC Supply from Kraal Well 1	Drinking Fountain in Main Office	
Rocky Point Port	Trucked Water	Domestic Tank Tap	
Waterloo Road Office	NWC Supply from Hermitage Dam	Tap in Office Kitchen/Pantry	

3.3.4.4.2 ANALYTICAL RESULTS

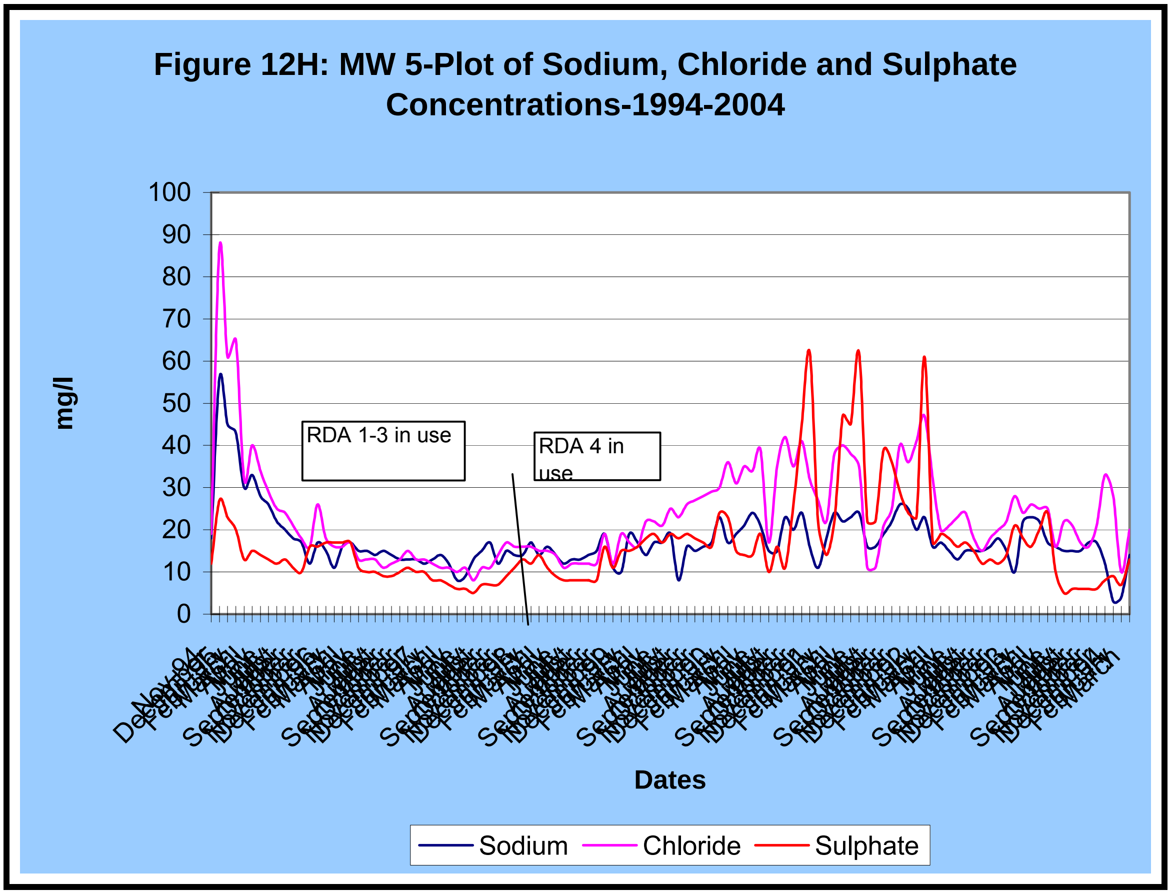
a) Borehole Profile

The samples collected from each borehole at 30 metre intervals during drilling indicate that no contamination resulting from the bauxite/alumina operations was detected in any of the wells. In several wells the sodium concentration was higher than normal but so was the chloride concentration. The Na:Cl ratios were at all times less than 1. It is noteworthy that neither Arsenic, Cadmium, Mercury, Selenium nor Silver was detected at any depth within any of the wells. Phenol was the only organic compound detected at one level in 5 of the wells and all at very low concentrations. No Volatile Aromatic Compound was detected at any concentration that exceeded the guideline values. No TPH was detected that would be a cause for concern.

b) Monthly Sampling and Analysis

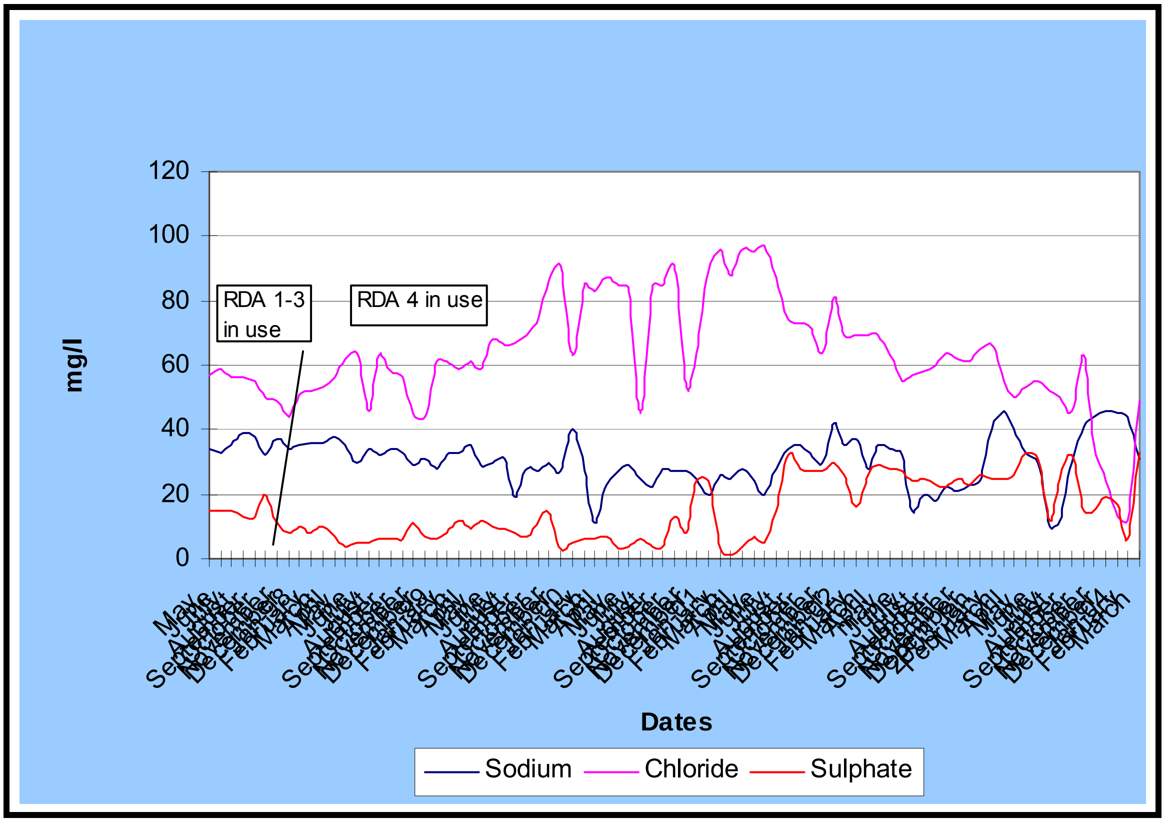
The results for the monthly sampling and analysis programme are shown plotted for four of the monitoring points-3 monitor wells and 1 production well. The points are MW 5 to the west of the RDAs; MW 9 to the east of the RDAs; MW 10 to the south of the RDAs and Hayes Public well located to the south of the RDAs and between MW 9 and MW 10. The Hayes Public well was selected, as this well is the source of the water supply for the Hayes community and has been the discussion of many community meetings as to its quality and suitability for domestic uses. The plots of the sodium, chloride and sulphate concentrations are shown as figures Figure 3-15 to Figure 3-19.

FIGURE 3-15: MW 5-Plot of Sodium, Chloride and Sulphate Concentrations-1994-2004



At MW 5, to the west of the RDAs, the data plot Figure 3-15 shows no significant increase in the sodium concentration over time. There is a close correlation between the chloride and sodium concentrations. In all cases the Na:Cl ratio would be less than 1. The assessment took into consideration the impact of each RDA as it was commissioned into service. As can be seen there was an increase in the chloride and sodium concentration after RDA was brought on stream. However, this is not due to leakage from the RDA but to the below average recharge coupled with increased pumping.

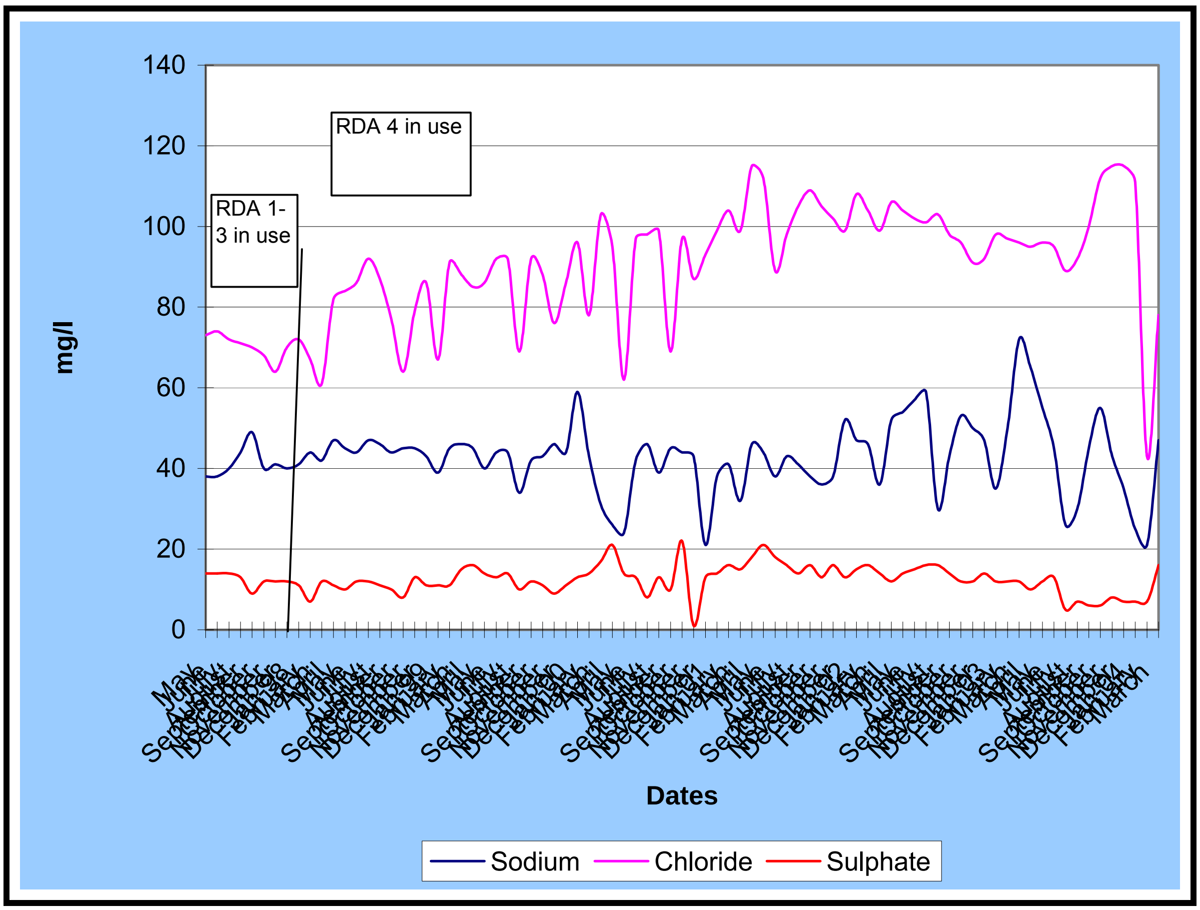
FIGURE 3-16: MW 9-Plot of Sodium, Chloride and Sulphate Concentrations-1994-2004



At MW 9, to the east of the RDAs, the plot Figure 3-16 while showing a varying concentration for sodium does not show a trend toward an increasing concentration. The chloride shows an increasing upward trend in concentration up to June 2001 where after there is a decline in the concentration. This increased chloride concentration is probably due to the less than average rainfall/recharge between 1999 to 2000 and the increased pumping to meet water demand. Here also the high chloride concentration compared to the lower sodium concentration would ensure that the Na:Cl ratio is less than 1.

The commissioning of RDA 4 did not lead to any increase in sodium concentration. The increase in chloride concentration is not attributable to the RDA but to recharge and pumping conditions and would most probably represent increased salinity of the groundwater during that period. An increase in the sulphate concentration after June 2001 was noted. This led to the concentration moving from less than 20 mg/l to between 20 to 30 mg/l. The reason for this is not known but the concentration is still far below the WHO guideline value of 400 mg/l.

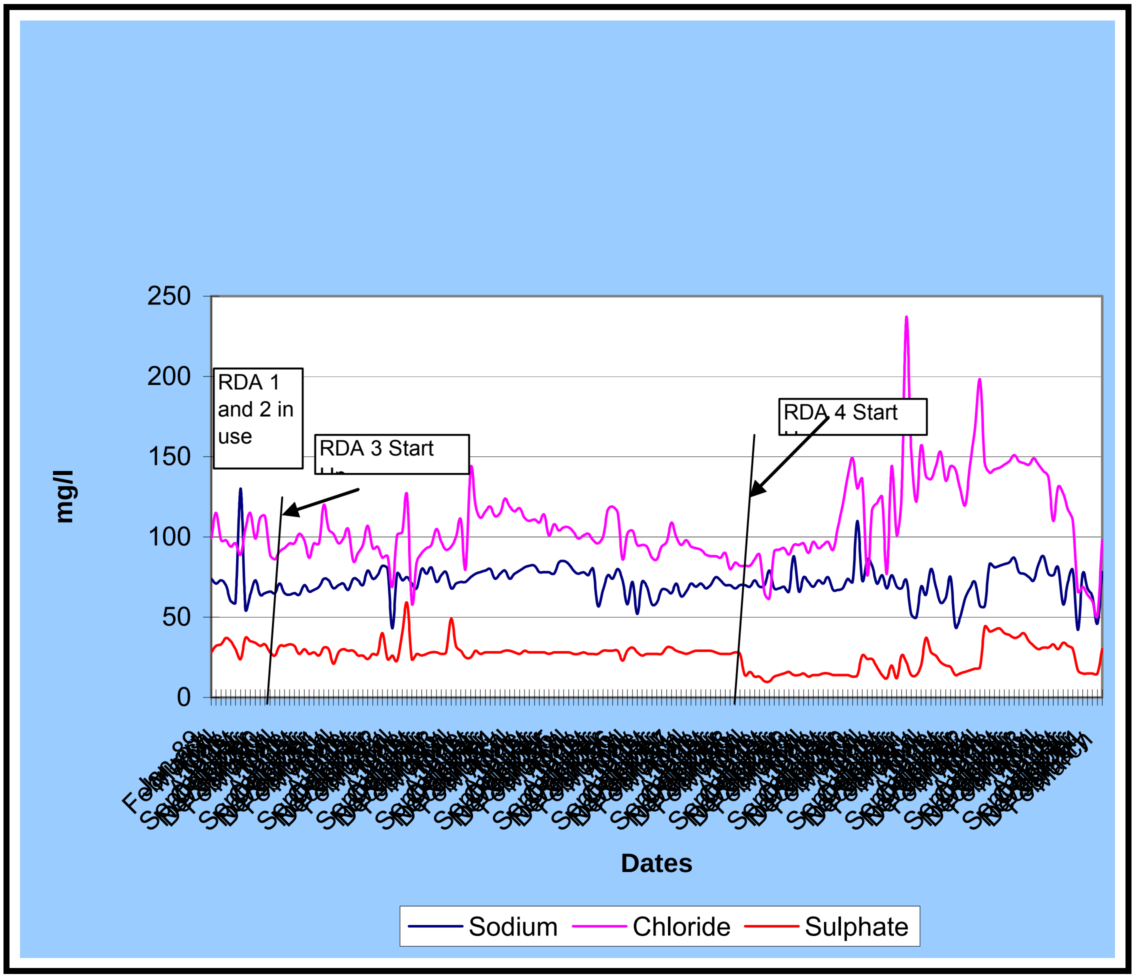
FIGURE 3-17: MW10-Plot of Sodium, Chloride and Sulphate Concentrations-1994-2004



At MW 10, to the south of the RDAs, the plot (Figure 3-17) there is a trend to an increase in chloride concentration. This well is located close to the Dry River 4 irrigation well that has reported chloride concentrations of up to 150 mg/l. There has not been a trend towards an increase in the sodium and sulphate concentrations.

The use of RDA 4 after 1998 has not resulted in an increase in the sodium concentration. As is the pattern with the other wells an increase in the chloride concentration was noted. However this is more related to salinity changes within the aquifer. There was no overall change in the sulphate concentration.

FIGURE 3-18:Hayes Public Well Plot of Sodium, Chloride and Sulphate Concentrations 1989-2004



At the Hayes Public well, also south of the RDAs, the plot Figure 3-18 shows a very constant concentration of sodium and chloride up to the year 2000. The chloride concentration has shown an increase since 2000 that again may be due to the below average recharge and increased pumping. The start up of RDA 3 and RDA 4 as shown on the graph did not in any way affect the concentrations of sodium and sulphate. This well is the most southern of the monitor points and is the closest to the South Coastal Fault and the wells at Hayes Common that show high chloride concentrations exceeding 350 mg/l at times. The Na:Cl ratio here would also be less than 1.

The controversy of the possible contamination of the Hayes Public well has led to many meetings between Jamalco and the Hayes community. The monthly sampling does not show any caustic contamination at the Hayes well. Further investigation was recommended and on April 1, 2004 a sample was collected and analyzed for heavy metals. The results are presented below in Table 3-11.

As can be seen only one parameter exceeds the World Health Organization (WHO) guideline value for drinking water. That parameter is Aluminium and the concentration was reported at 0.22 mg/l while the guideline value is 0.20 mg/l. Aluminium has no toxicological effect on the human body. The concentration of Copper was reported at 0.011 mg/l with a guideline value of 1.0 mg/l. Barium was reported at 0.055 mg/l. There is no guideline value for Barium. All the other thirteen parameters had concentrations less than the Laboratory Reporting Limit (LRL).

The conclusion reached is that the water quality at the Hayes Public well meets the drinking water guidelines and is suitable for use as a domestic water supply. The bauxite/alumina operations have not impacted on the water quality in the limestone aquifer to affect that being abstracted at the Hayes Public well.

TABLE 3-11: Analytical Results of Heavy Metals for Hayes Public Well (NWC) – April 2004

Parameter	Concentration (mg/l)	Lab Reporting Limit (LRL) (mg/l)	WHO Guideline Limit for Drinking Water (mg/l)	Remarks
Aluminium	0.22	0.10	0.20	Exceeds Guideline-No toxicological Effect.
Antimony	<0.50	0.50	0.002	
Arsenic	<0.50	0.50	0.05	
Barium	0.055	0.010	None	
Beryllium	<0.0050	0.0050	None	
Cadmium	<0.010	0.010	0.005	
Chromium	<0.020	0.020	0.05	
Copper	0.011	0.010	1.0	
Iron	<0.10	0.10	0.3	

Parameter	Concentration (mg/l)	Lab Reporting Limit (LRL) (mg/l)	WHO Guideline Limit for Drinking Water (mg/l)	Remarks
Lead	<0.10	0.10	0.05	
Manganese	<0.010	0.010	0.1	
Mercury	<0.00020	0.00020	0.001	
Nickel	<0.020	0.020	None	
Selenium	<0.50	0.50	0.01	
Thallium	<0.50	0.50	0.006	
Zinc	<0.020	0.020	5.0	

The analytical results for the quarterly sampling done in April 2004 are included as Figure 3-11 and Table 3-13 The sodium concentration reported for monitor well 1 and shown in Figure 3-11 incorrect and is not in keeping with previous historical results reported. This high sodium concentration and the lower chloride concentration yields a Na:Cl ratio of 2.73 which would indicate caustic contamination. However this well is located north and upgradient of the REFINERY. It is outside the zone of contamination from the bauxite/alumina works and saline intrusion. The duplicate sample analyzed by Jamalco reported a sodium concentration of 8 mg/l and chloride concentration of 12 mg/l with the Na:Cl ratio at 0.67 which is more in keeping with the historical results reported since 1994.

The iso-sodium plot for April 2004 is shown as Figure 3-19. Sodium concentration varies from 50 mg/l to over 250 mg/l west of the RDAs. The contours of the highest sodium concentrations (250 mg/l) match those areas where saline intrusion is met at depth in the wells-MW 6 and 8.