Unit 3 – Water Resources

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Preamble

The Maltese islands including Gozo have a typical island hydrology. This unit provides an overview of the main hydrological parameters: rainfall, evaporation, runoff and groundwater storage. Understanding the dynamics of natural recharge, sea-water intrusion, water extraction and land use practices is important to safeguard both the quantity and the quality of the island's fresh water resources.

> ***"Sir, I have inspected the Malta Water Works and I find that they are in a highly satisfactory condition."***
> correspondence from Mr. Osbert Chadwick, dated 10th January 1896, reporting to Count. G. Strickland, Chief Secretary to Government

Rainfall/precipitation

Official rainfall records are kept by the Meteorological Office of the Department of Civil Aviation at Luqa (Malta). The meteorological records at Luqa started in 1947, although it is noteworthy that the earliest rainfall records on the island date back to as long ago as the 1850s. The average annual rainfall over the past 60 years amounts to around 530 mm, which is registered during an average of 85 days with rainfall per year. More detailed analysis however shows a very high year-to-year variation from these annual figures. Rainfall is usually heavy at the onset of the rainy season, during the month of October, while the bulk of the rainfall occurs mainly during the months of November, December and January.

The regional distribution of rainfall over Malta and Gozo can be analysed using data by means of a number of rain gauges distributed all over the Islands. In Gozo these gauges are found in Għasri, Victoria, Xagħra, Xewkija, Nadur and Mġarr. Studies carried out by Chetcuti et al (1992) on meteorological records over the period 1956 to 1986 imply that there is no significant difference in rainfall between the lowlands and the highlands of the Maltese Islands.

Local rainfall records do not show evidence of climate change as clearly as in other regions around the Mediterranean, where the annual rainfall generally shows a reduction of about 10% in recent years. Analysis on the basis of average figures disguises the variability and the unpredictability of rainfall in the Maltese Islands on a year-to-year basis. Typically, the annual rainfall is derived from only a small number of rainstorms, and year-on-year variations are extremely high. Moreover, the intensity of the rainfall during these rainstorms leads to very rapid runoff of the water into the sea.

Runoff/Evapotranspiration

Owing to the Islands' prevailing climate, characterized by strong breezes and long hours of sunshine, a major part of the rainfall is rapidly evaporated from the surface or lost through transpiration from the vegetation. In addition, a very substantial amount of rainwater, especially during heavy rainstorms, is lost as runoff to the sea from urban areas via sewers or directly from bare rock, roads and valleys. Sivarajasingham (1971) argues that runoff losses to the sea are probably even greater on the island of Gozo since "the watersheds here are more open, and a higher proportion of areas are directly sloping to the sea".

In the absence of perennial streams, the scarcity of fresh water has been an acute problem for many centuries. This scarcity is more apparent during the summer period, when the water availability has traditionally depended on the efficient collection and storage of rainfall during the rainy season.

Some of the runoff is appropriated by numerous roof catchments, channels and diversion drains constructed to capture this surface runoff. Mostly all farmhouses have excavated underground wells and cisterns to store the water thus collected, which is commonly used as supplementary water for irrigation. This form of 'runoff harvesting' has been practiced on the Islands since antiquity. Several tanks for the storage of fresh water have been discovered dating back to **Punic** and **Roman** times. However it was during the time of the **Arabs** that water extractions by means of animal driven devices were introduced. These are better known as the water wheel or '***Sienja***' in Maltese. The **Knights of St. John** made runoff harvesting a basic design feature of every house being constructed.

Remains of aquaduct on road to Gharb from Victoria

Runoff harvesting during the time of the Knights of St. John

Before the Knights of St. John came to the Islands, in 1530, the water resources of the Archipelago were described as being "salty and sedimentary" by the delegation that was sent to check on the existing conditions on the Islands. The delegation observed that "the local population stored water in cisterns and even in ditches". After the founding of Valletta by the Knights in 1566, several measures were taken to conserve water resources. The provision of fresh water was considered to be of paramount importance to the inhabitants of Valletta since the lack of it could have drastic consequences especially during a siege. Thus regulations were set up to prohibit gardens in the city and to **enforce the construction of a well** (***bir***) **in every house**. These measures were, however, insufficient and several attempts by various grandmasters followed to further secure the water supply in the city. *(Source: Morris, 1952)*

Streams/Water courses

Today there are no perennial rivers or streams in the Maltese Islands, however the seasonal rains do give rise to seasonal flows. These water flows are important for the recharge of the underlying aquifers.

The background information layer in the Thematic Map for this Unit provides a 3-dimensional view of the topography of the island of Gozo. The map was created by (hypothetically) placing the sun in the northeast – and the areas which are facing the sun have been made to appear 'lighter', while areas on the downhill side have been made to appear 'darker'. Subsequently, the map has been used to determine the respective catchment areas.

Source of illustration: Wikipedia

A **catchment area** includes both the stream and its various branches/channels that convey the water as well as the land surfaces from which the water drains into these channels.

Each **catchment area** is separated topographically from adjacent catchment areas by a ridge or a hill, which is known as a water divide or watershed.

The watershed map in the Web-GIS shows the water divide between the different catchment areas. The largest catchment area, 'Wied Marsalforn' includes the central part of the island which drains into the sea to the north. The term '***wied***' refers to the valley (plural '***widien***'). The table below lists the 'larger' of around 40 distinct catchment areas that are found on the Island of Gozo in descending order of their respective catchment area.

Main Catchments	Surface Area (Km2)	Main Catchments	Surface Area (Km2)
Marsalforn	11.5	Mġarr	1.8
Ramla	6.3	Daħlet Qorrot	1.8
Xlendi	5.3	Wilga	1.5
Mġarr ix-Xini	5	Biljun	1.1
Ilma	4.5	Raħeb	1
Mielaħ	3.9	Sabbar	1
Għasri	3.3	Pergla	0.9
Qliegħa	2.8	Xilep	0.3
San Blas	2		

(*Wied*) Marsalforn Valley

Infiltration and percolation

Malta's fresh water resources are recharged by rainwater following infiltration into the soil followed by (deeper) percolation through the porous limestone rock. This process is responsible for recharging the aquifers from where the water either seeps out or is extracted. Studies carried out by Morris (1952), Newbury (1968), and Chetcuti (1988) have consistently shown that only an estimated 16 to 25 percent of the annual rainfall percolates through the porous limestone rock to recharge the islands' aquifers.

As far back as the 1880s, many small dams have been built across watercourses and are aimed at retarding the flow and thus to retain the water within the valleys '***widien***' for longer periods to allow increased infiltration and percolation into the limestone.

Osbert Chadwick, a pioneer the islands' water resources management

Between 1883 and 1897 engineer Osbert Chadwick devised several programmes which were aimed at addressing the islands' chronic water supply problems. The loss of surface water runoff into the sea led Chadwick to propose that "small masonry dams be constructed at suitable points in all '***widien***' with an adequate catchment to appropriate the surface run-off during winter rains". True to his life-long motto: "the first duty of an engineer is to make a measurement, his second to make a better one", Chadwick went on to advise that "the ultimate height of each dam was to be determined experimentally, commencing with a low dam, and increasing its height according to the actual results observed from year to year". *(Source: Morris, 1952)*

Aquifers

The islands' aquifers, also termed fresh water bodies, refer to the layer within the rock formation which is saturated with the water which has percolated from the land surface.

Owing to the islands' geology, all aquifers are limestone aquifers. However, it is possible to distinguish between the islands' aquifers according to their hydrogeological characteristics.

The two main categories of aquifers which are found in the Maltese Islands are the so called 'mean sea level' and 'perched' aquifers respectively. As its description suggest, the former type of aquifer is found at sea level. Owing to its lesser density, the fresh water body within the rock formation finds itself "floating" on seawater. The Gheyben-Herzberg principle, which is based on the difference in density between fresh water and seawater, advises that for every one meter of fresh water above sea level, it can be expected to find up to 36 meter of fresh water within the rock formation below sea level. The natural drainage of this aquifer occurs all around the coastline, and hence this aquifer takes the form of a lens-shaped body. In Gozo, the Mean Sea Level Aquifer extends over the whole island with the exception of a small area in the south-eastern part of the island around the Mġarr harbour.

The perched aquifers owe their existence to the presence of the Blue Clay formation. The latter acts as a seal to the deeper infiltration (= percolation) of water from the land surface. The overlying, porous and fissured Upper Coralline Limestone allows for substantial amounts of water to be retained in the Upper Coralline and (where present) Greensand aquifers. Thus, these aquifers are literally 'perched' on the top of the Blue Clay.

The table below provides an overview of the perched aquifers in Gozo, their aerial extent, the names of the main springs as well as the means of extraction and main use of the water.

Perched Aquifers	Surface area (km2)	Major Springs	Means of extraction (*)	Main use
Għajn Abdul	0.12	Għajn Abdul		Agriculture
Għajnsielem	2.88		224 private wells 1 borehole for public supply	Agriculture
Għar Ilma	0.10	Għar Ilma		Agriculture
Kerċem	0.29		old wells and a number of galleries	Domestic
Nadur	4.88		427 private wells and 37 springs	Agriculture
Victoria and Fontana	1.05	Għajn il-Kbira	old wells and a number of galleries	Domestic
Xagħra	3.02		475 private wells and 15 springs	Agriculture
Żebbuġ	0.38		82 old wells (*spejjer*)	Domestic

(*) Figures obtained from MRA (Malta Resources Authority), 2005, *Initial Characterisation of Groundwater Bodies*

Springs

Rainwater that infiltrates and percolates through the rock goes to recharge the aquifers and either emerges as seasonal springs or is extracted for public use. Fresh water, seasonal springs seep out from the perched aquifers at the interface between the Upper Coralline limestone and the Blue Clay formation.

The storage capability of the perched aquifers depends on the surface area and thickness of the Upper Coralline outcrops. As noted by Vella (2006) the perched aquifers of Xagħra, Nadur and Għajnsielem-Qala have the capability to store larger volumes of water compared to the aquifers found to the west of the island. Consequently, many of the springs arising from these smaller aquifers, including Għajn Abdul and Għar Ilma, have a heavily reduced or insignificant flow during the dry summer months, while those flowing from the larger perched aquifers found on the eastern side of the island maintain a more abundant flow throughout the year.

Fontana

Fontana is a suburb of Victoria on the Rabat-Xlendi road. Its local name "***Triq tal-Għajn***" (the way to the spring) is referring to a spring found at the bottom of the road leading to Xlendi, known locally as "***il-Għajn il-Kbira***" (the big spring). The word "fontana" comes from the latin word **fons** and refers to a source, a fountain, or a spring. In the sixteenth century arched shelters were built over the spring for the convenience of the people washing their clothes in these springs.

Nowadays, the word "***għajn***" is more frequently used. The semitic word "***għajn***" also refers to a freshwater spring or a source of water. Historically "***għajn***" was a communal watering hole whereby people used to abstract water for consumption purposes. Several place names across the Maltese Islands have this word in their names. e.g. ***Għajn Abdul, Għajnsielem***

Springs discharging water from the perched water tables in the Upper Coralline Limestone/Blue Clay interface, as well as shallow wells tapping water from the water tables in the lower parts of the main valley systems have been drawn upon since ancient times. Today, the yield from springs accounts for less than two percent of the volume of groundwater which is exploited annually.

Ghammier Spring

Underground Galleries and Boreholes

The extraction of groundwater from the Mean Sea Level aquifer is achieved through a system of underground galleries and boreholes. In 1952, Morris lists two main civil engineering works for the extraction of water from the Mean Sea Level aquifer in Gozo: 'an older line of galleries, of total length 4610 feet along ***Wied Imġgarr ix-Xini*** (Mġarr ix-Xini Valley) on the southern side of the island, and a newer line, of total length, 6020 feet, much of which was constructed during the war years, along ***Wied ta' Marsalforn*** (Marsalforn Valley) on the northern side of the Island'. These galleries refer to underground tunnels cut into the rock just above the mean sea level datum, whereby the excavation proceeds from a shaft and the tunnel is excavated away from this shaft while maintaining a slight gradient. This technique assures that the water collected in the tunnel flows by gravity to the shaft from where it is pumped to the surface. In Malta, several of these underground galleries form a star-shaped pattern around a central shaft, while other galleries (like the ones in Gozo) were dug along the natural course of the valleys.

The 1970s saw the advent of a large-scale programme of borehole drillings across both the island of Malta, Gozo and Comino. Drilling typically consisted of around 0.50m diameter cores and pumps installed at the bottom of each borehole bring the water to the surface.

Their operation requires that a sufficient height of water is maintained at all times above the pump inlet. In practice, this implied method of extraction requires the pumps to be installed quite below the mean sea level. While the underground galleries supplied only what was being collected by gravity, the boreholes could (at least in theory) supply water at a constant rate all year round. In reality, this 'new' method quickly led to increased levels of salinity in the water being extracted. The mode of operation compromises the 'natural equilibrium' between the fresh water body and the seawater below, thus leading to increased levels of sea-water intrusion in the Mean Sea Level Aquifer.

The Malta State of the Environment Report (SOER, 2005) confirms that major groundwater bodies in the Islands are being over-abstracted or are dangerously close to being over-abstracted. The report also confirms that the over-extraction from the Mean Sea Level aquifer leads to seawater contamination due to upconing. In the same year, the Malta Resources Authority estimated that the groundwater abstraction in Gozo was producing an overall negative balance of –1.12hm^3.

Drinking Water Supply

The Mean Sea Level aquifer is the only aquifer in Gozo which is exploited for drinking water supply purposes. The equilibrium of this 'lens' is in a state of flux depending on the fluctuations in rainfall and tidal effect. It is highly doubtful that the well-known Gheyben-Herzberg principle correctly represents this aquifer today. The ever increasing exploitation of this aquifer, especially since the advent of the borehole drilling programme in the 1970s, has resulted in upconing of salt water at the sites of extraction.

The National Statistics Office (2004) reported that extraction from boreholes in Gozo accounts for as much as 91% of the total water abstraction for drinking water supply purposes, with only 9% being produced by underground galleries.

Timeline – Pioneers of Water Supply Development

1883-1897	Engineer Osbert Chadwick first came to Malta in 1883, where he remained for 4 years working on the development of the Water Supply. Chadwick was given all possible help locally to put his theories into practice and he continued paying periodic visits to Malta which enabled him to witness the implementation of many of his proposals. He gauged springs, recorded run-off water, studied existing wells and galleries of the Upper Water Table, the distribution network and storage facilities. He drew up many reports on Malta's water situation, advocated the need for Underground Water Legislation and the setting up of water catchment areas. Chadwick also discovered the 'White Rock' which is still sometimes referred to as the 'White Rock of Chadwick'. In reality this is the porous and water bearing lower coralline limestone which contains the fresh water lens just above the mean sea level.

1909	Outbreak of Typhoid fever Sir Temi Zammit, Government Analyst and Major A.H. Morris, Sanitary Officer of the Malta Command started the sterilization of the public water supply by means of chlorine. Thus Malta adopted the sterilization of its water supply system within a few years of the introduction of this method in 1905 in the United Kingdom. Routine bacteriological and chemical analyses of the water supply have been undertaken by the Public Health Department since 1912.
1947-1952	Captain T.O. Morris who had submitted many reports in 1947 on the Water Supply Position in Malta finally drew up a comprehensive report on "The Water Supply Resources of Malta". This most knowledgeable report was the fruit of the author's many years of experience and studies of the hydrogeology of the island. The subjects treated include the Water Cycle, the Development and Conservation of the Mean Sea Level Aquifer, the Re-organisation of production, storage and distribution, irrigation and sewage utilization, and the prospects of deep boring below mean sea level.

Source: adapted from commemorative booklet, Seminar on selected water problems in islands and coastal areas, Malta 5-10 June 1978

Vulnerable Groundwater Resources

According to the Malta State of the Environment Report 2005, a 'preliminary risk assessment carried out by the Malta Resources Authority indicates that, with the exception of the Comino Mean Sea Level aquifer system, all Malta's groundwater bodies are at risk or probably at risk of failing to meet the objectives of the (European) Water Framework Directive. **Malta's groundwaters are seriously at risk from overexploitation and pollution, risking the loss of Malta's only renewable freshwater resource'**.

The European Water Framework Directive

The European Water Framework Directive [EWFD] requires progressive protection and enhancement of rivers, lakes, estuaries, coastal waters and wetlands by the year 2015. The theme of the Directive is that the use of water by humans should be sustainable and not impact unduly on flow, volume and storage and the chemical, physical or ecological quality of the natural water environment.

Among other obligations on Member States, the Directive calls "to encourage the active involvement of all interested parties in the implementation of the Directive", i.e. relevant government departments, local communities, water utilities, industry and commerce, agriculture, consumers and environmental groups in the discussion of the river basin management plans.

Private water extraction makes it very difficult to get a detailed and precise picture of the state of the groundwater in Gozo. As evidenced in the table above, there are a substantial number of private wells which are extracting water from the perched aquifers. These private wells do not record the extraction rates, yet their impact on the (reduced) recharge of the underlying Mean Sea Level aquifer, through deeper percolation, cannot be overlooked. Recharge to this aquifer is predominantly through fissures in the overlying Globigerina Limestone. A smaller part of the recharge is derived from the water which percolates through the Blue Clay formation (although the Blue Clay generally acts as a seal as mentioned earlier, this is not a strictly ‘hermetic’ seal and some of the water stored in the perched aquifers does succeed to percolate to the underlying Mean Sea Level aquifer). A detailed estimation of the sustainable yield of the Mean Sea Level aquifer is further complicated by the absence of piezometric data, i.e. measurements of the height of the water table at regular distances across the aquifer. Groundwater modelling which could be used for example, to simulate the behaviour of the aquifer under different extraction ‘regimes’, becomes problematic in the absence of direct piezometric observations.

The highly fissured limestone makes the possibility of sea water intrusion into the Mean Sea Level aquifer a permanent problem, yet the over-abstraction of the aquifer has clearly exacerbated the problem to an alarming level. This highly fissured nature of the limestone also brings us to the ‘special’ vulnerability to pollution that karst aquifers can be subjected to. Derek Ford (1989) advises that ‘Karst aquifers are notoriously effective in transmitting rather than treating pollutants. This arises from the unfortunate fact that the relatively large capacity for self-treatment found in many groundwater systems is comparatively poorly developed in karst’.

The sources of pollution are as many and as varied as there are human activities taking place above the aquifers! One possible approach is to distinguish between domestic, industrial and agricultural sources of pollution.

Most villages are found on top of the perched aquifer systems, which offer a natural barrier to the percolation of contaminants to the Mean Sea Level aquifer below. Major exceptions are the villages of Xewkija, Sannat, Kerċem, Santa Lucia and Għarb. The Industrial Estate which is found in Xewkija represents a different yet important threat to the Mean Sea Level aquifer. Agricultural practice has long been characterized by an extensive and liberal use of fertilizers and pesticides which have a negative effect on human health and ecosystems. Farm effluent is another widely dispersed pollutant in Gozo, particularly from pig and cow farms.

The dumping of waste is a major source of concern. Derek Ford (1989) alerts that 'Unfortunately, in all inhabited karsts (around the world), dolines and sinkholes are perceived as being particularly suited for the dumping of solid or liquid waste, because it disappears underground and 'out of sight is out of mind!' As elsewhere in the Mediterranean, besides dolines and sinkholes, it is often whole valleys that are the 'preferred' target for the illegal dumping of waste!


Quarrying at Dwejra

Evidently without adequate protection measures, even regulated landfills present a major problem. A heritage conservation area, which appears to be under particular threat, is found in Dwejra. This major tourist attraction is in close proximity to a landfill, which is growing at an alarming rate. Besides damaging the aesthetic beauty of the area, it also threatens to pollute the marine environment from leachates reaching the sea.

A major threat to the quality of ground water, as mentioned in the Unit on Geology, is derived from quarrying activity (= physical removal of the natural filtration medium), and worse, when a disused quarry becomes the object of landfilling that is not strictly monitored to receive inert waste only.

Thematic Map and related Information Layers for Unit 3

The Thematic Map associated with Unit 3 in the WebGIS is made up of the following information layers:

Gozo DEM: raster map showing a 3-dimensional view of the topography of Gozo

Gozo Catchment Areas: segment map showing the water divide between the different catchment areas in Gozo

Gozo Water Courses: segment map outlining the main water courses in Gozo

Gozo Springs: point map showing the location of the main springs in Gozo

Other information layers available in the WebGIS include:

Gozo Aquifers: polygon map showing the distribution of the main aquifers in Gozo

Gozo Perched Aquifers: polygon map showing the distribution of the perched aquifers only

Gozo Catchments: point map showing the names of the **main catchments** in Gozo

Layers	**Type**	**Visible**	**Selectable**	**Attribute data (short name)**	**Attribute data (description in full)**
Gozo DEM	Raster	Yes	Yes		
Gozo Catchment Areas	Segment	Yes	Yes		
Gozo Water Courses	Segment	Yes	Yes		
Gozo Springs	Point	Yes	Yes + show labels		
Gozo Aquifers	Polygon	No	Yes	Type	Aquifer Type
				Area(km^2)	Surface area in km^2
Gozo Perched Aquifers	Polygon	No	Yes		
Gozo Catchments	Point	No	Yes + show labels		

Useful Weblinks

http://geography.about.com/library/maps/blmalta.htm
http://users.aber.ac.uk/jpg/malta/virtual.html
http://www.agric.gov.mt/
http://www.emwis-mt.org/documentation/Context/Physical%20factors.htm
http://www.gozo.com
http://www.gozo.gov.mt
http://www.islandofgozo.org
http://www.maltaweather.com/climate.shtml
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