The hydrology and hydrogeology of Aammiq Marsh

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1. Background

1.1 Geography

Aammiq Marsh (33° 44' N, 35° 47' E) is situated in the Bekaa Plain, a fertile plain 10-30 km wide that stretches between the Lebanon and Anti-Lebanon mountain ranges at an altitude of 850-1100 m a.s.l. (Fig. 1). The two mountain ranges run parallel to each other in a NNE-SSW direction, rising steeply from the eastern shores of the Mediterranean Sea. The marsh (863-865 m a.s.l.) lies on the western side of the plain, at the foot of the Lebanon Range (here called the Barouk Ridge).

1.2 Hydrology overview

The western (Lebanon) range is the higher of the two ranges throughout most of its length, and reaches an altitude of about 1900m behind Aammiq. Oriented NNE-SSW, this range rises steeply from the eastern end of the Mediterranean Sea, and presents a formidable barrier to moist winds blowing eastwards across the Mediterranean. This causes high rainfalls on the west-facing slopes (up to 1400 mm/year) and at high altitudes on the east-facing slopes, and creates a rain shadow in the Bekaa plain (as low as 200-600 mm/year in the northern parts; Sene *et al.*, 1999). Fifty kilometres south of Aammiq, however, the Lebanon range drops to only 525 m, while Mt. Hermon in the Anti-Lebanon range rises to 2814 m. This topography allows moist southwesterly winds to enter the Bekaa, and supply rain to the southern Bekaa, including the Aammiq region. Therefore, Aammiq receives an annual rainfall of 700-880 mm (Walley, 1997), near the national average of 800-1000 mm (Sene *et al.*, 1999), whereas the mountain slopes above the marsh receive 1500-1600 mm annually.

Rainfall in Lebanon is highly seasonal, with 90% of the rain falling between November and April (Lebanese Ministry of Environment, 2001). Typically no rainfall at all occurs from June to August. Therefore, water usually is in excess during the months of January to March, when the agricultural fields around the marsh are often flooded, and scarce during the months of May to November.

Direct precipitation to the Bekaa Plain is not sufficient to maintain a wetland, and, especially after the wettest months have passed, Aammiq Marsh depends on ground water derived from rain and snow-melt on the slopes of Jebel Barouk. This water emerges as springs at the foot of the mountain, the western end of the marsh (Fig. 2), and from there flows eastwards approximately 3.8 km to the Hafir River, which then joins after about 1400 metres to the Litani River. The Litani ultimately carries this water to Lake Qaraoun, and from there to the Mediterranean Sea near Tyre (Fig. 1). Between the western springs and the Hafir River, the water in Aammiq Marsh spreads across an area of about 70-100 ha, reaching a maximum depth of about 3 m (see Fig. 3).

Apart from these springs, several other water sources potentially contribute water to the marsh (Fig. 2). Three springs that emerge about 300 m higher on the Barouk slopes (Ain el-Tine, Ain el-Abed and Ain es-Saalouk) produce streams that historically have reached the marsh. However, at present all water from Ain el-Tine and a large proportion of the Ain el-Abed flow is diverted for domestic supply in three nearby villages, and during the summer months, Ain es-Saalouk and the remainder of the Ain el-Abed flow is used for irrigation. Thus, at present little if any water from these springs reaches the marsh. Direct precipitation from the fields to the north and south of the marsh also potentially brings water to the marsh, but the exact boundaries of the catchment on the plain are difficult to locate, as the ditches directing runoff water across the plain are constantly being closed and reconnected. Typically, the pattern of drainage ditches north of the marsh means that most water falling in this area flows directly to the Hafir River, but three large ditches sometimes connect the northern fields to the marsh, and potentially bring water during the wet season (as shown in Fig. 2). South of the marsh, rain falling within the catchment area (Fig. 2) is channelled into the Riachi River that connects with the main marsh near its western end. The Riachi River itself is divided by small earth barriers about midway along its length (Fig. 2) so that in its western half it directs water to the head of the marsh, whereas in its eastern half it directs water to the Litani River.

Surface outflows from the marsh to the Hafir River are complex because the Hafir and one or two large ditches intersect with the marsh at more than one point. However, we can simplify the picture by defining the marsh outflow a little further west where the marsh constricts to pass beneath a bridge (see Fig. 2). It is reasonable to define the marsh outflow here, since almost all of the marsh water passes through this narrow channel, and east of this point, the marsh remains narrow and river-like until it meets the Hafir. West of this outflow there are other ditches that are opened at certain times to drain water from the marsh. These are marked in Fig. 2. On an annual scale, however, the amount of water exiting via these pathways tends to be small compared with the main outflow.

1.3 Geology and hydrogeology

The geology of the area has been described in detail by Walley (1997; 2003), but will be summarised briefly here as it relates to water flow patterns in the region. The local geology can be divided broadly into two types; the mountain slopes are limestone (calcium carbonate), overlaid by very thin soils, whereas the floor of the plain is composed of deep sedimentary deposits of alluvial (river) and lacustrine (lake) origin. The limestone mountain presumably extends beneath the plain, but its steep slope means that only a few hundred metres across the valley, the depth of the sedimentary deposits is well over 300 m (local well-drillers, pers. comm.), and possibly reaches more than 2000 m in the middle of the plain (Walley, 1997).

The limestone mountain slopes form an excellent aquifer as they are deeply penetrated by fissures through which ground water can flow rapidly. Although essentially a single rock type, the limestone has a very complex structure that affects the movement of ground water. First, the limestone is heavily folded, which alters the orientation of the fissures, and hence the direction of ground water flows. This makes it very difficult to determine the boundaries of the water catchment for Aammiq Marsh, though Haas (1954) has estimated the approximate catchment size as 20-30 km^2. The anticline behind the head of Aammiq Marsh that forms Qalaat el Mdiq (Fig. 2) is an important example of complex folding that alters the direction of ground water flows in the vicinity of the marsh. Second, in the Aammiq region three fault lines run parallel to the mountain ridge, the lowest at the level of the plain and the highest about 300 m above the plain (there may be more fault lines above this, too; Walley, 2003). The highest of the three represents an impermeable barrier to groundwater flow, causing the ground water to upwell at three points, known as Ain el-Tine, Ain el-Abed and Ain es-Saalouk (see Fig. 2). The lowest fault line is associated, in the vicinity of Qalaat el-Mdiq, with an outcropping of hard cretaceous rock that may be responsible for the ground water upwelling that feeds Aammiq Marsh.

The sedimentary deposits in the plain are not well known. Kolars and Naff (1993) makes the comment that impervious alluvial deposits in the Bekaa Plain prevent deep percolation and create a shallow aquifer, but water wells on the plain at Mansoura, Ghazze and the Houch Aammiq appear to contradict this. Recent work as part of this hydrological report has provided some knowledge of the various strata, their water-carrying properties and connection to the limestone aquifer, and these findings are reported in Walley (2003).

1.4 Land and water use in the Aammiq Region

Aammiq Marsh, as it currently exists, is a small remnant of extensive wetlands that once covered a large proportion of the Bekaa Plain. According to local people, these wetlands once stretched as far north as Zahle, 30 km north of Aammiq (Fig. 1). As has commonly occurred throughout the world, the wetlands have been progressively drained and converted to agricultural production since ancient times (the word Bekaa itself means quilt in the Phoenician language, which presumably means that large parts of the plain have been cultivated since Phoenician times, at least 2000 years ago). The exact history of drainage and conversion to agriculture is difficult to determine, but certain historical records can provide a rough framework. We know, for example, that during the French mandate (1930-40), plans were made to drain 11,000 ha of the southern Bekaa Valley and Qasmieh (a small area of coastal plain at the outflow of the Litani; Abboud, 1969). We also know that as late as 1969 there was still more than 5,000 ha of at least seasonally flooded land immediately north of Jib Jannine (not more than 8 km southwest of Aammiq Marsh; Fig. 1) which a project to straighten and levee the Litani River was supposed to "correct" (Abboud, 1969). An FAO report dating from 1967 confirms that the southern part of the Bekaa Plain at this time was "marshy" and "rarely cultivatable." Irrigation in the Bekaa Plain was already well under way by 1959, with irrigated crops on 9,400 ha of the Litani River Basin (about 20% of its land area) at this time (FAO, 1967). However, in 1959, and up until 1969, ground water sources were little used; most water wells in existence were shallow pits that tapped near-surface water (FAO, 1967; Abboud, 1969). The 1960s and early 1970s saw a major effort to improve the Bekaa Plain for agricultural production (Amery, 2003a,b), with drainage ditches dug, levees built around the Litani River to prevent its waters spilling across its floodplain after heavy rains, and more than

30 deep boreholes dug in the Qab Elias area alone (Diab Mdawwir, Aammiq Village, pers. comm.). During the Lebanese Civil War (1975-1990) little development occurred in the Bekaa (Amery, 2003b), but following the end of the war in 1990 there has been renewed digging of wells in the area. These engineering works have changed the hydrological regime of the plain drastically. Winter flooding of low-lying lands on the plain has been greatly reduced such that at present, these lands are submerged for only a day or two following the heaviest winter storms. Summer ground water levels in the region also have dropped 3-4 m in the last 20 years (Walley, 1997) as a result of the increasing number of boreholes.

These changes have affected Aammiq Marsh. Maps dating back to 1939 show the extent of the marsh as significantly greater than it is today (Walley, 1997), though maps drawn in the 1950s show the marsh boundaries very close to their present position. The major change to Aammiq Marsh in the last 30 years is that the once perennial surface waters now disappear almost completely for 5-6 months each year. Probably this is mostly the result of ground water abstraction through deep boreholes in the region. The Skaff Estate, which owns two-thirds of the marsh area and large areas of surrounding agricultural land, installed 18 boreholes on their property between 1990 and 1999, adding to the older boreholes in the Qab Elias area, a few kilometres north of the marsh. Water is also abstracted directly from the marsh itself through one fixed pump on the Hajj Chahine-owned part of the marsh (Fig. 4), and from time to time, mobile pumps withdraw water from ditches directly connected to the marsh (Fig. 5).

Other past changes to the marsh hydrology have been reversed in recent years. For many years, water was pumped directly from the marsh springs below Qalaat el Mdiq to irrigate fields north of the marsh, but this ended about 10 years ago. In the 1990s, a deep ditch was dug along the northern boundary of the main marsh ("Northern ditch"; Fig. 2) to dry a large shallowly-flooded area to the north for agricultural production. The ditch was closed in 1998, which significantly increased the water depth and flood duration of the main marsh, and in 1999 the field was returned to marshland ("Reclaimed area"; Fig. 2), adding about 20% to the total extent of the marsh.

1.5 Current and future water issues in the Bekaa

The area of the Bekaa south of the Beirut-Damascus highway accounts for 43% of all irrigated cropland in Lebanon, with another 24% in south Lebanon dependent on water availability in the Bekaa (Kolars and Naff, 1993). Therefore water demand already is high in the valley, where current usage exceeds natural rates of ground and surface water recharge by 50% (Karam and Karaa, 19??). This has led to a measurable decline in the water table beneath the plain in recent years. Irrigation methods currently used in the Bekaa are often inefficient. Low-cost techniques for water delivery, such as open ditches and "gun" sprinklers (see Fig. 18) are almost always favoured over higher-cost efficient technologies such as drip irrigation. Also, because much of the irrigation equipment is used intensively, its use continues during the hottest and windiest part of the day, during which time much of the irrigation water is lost to high evaporation.

Furthermore, water usage in the Bekaa is likely to increase in the future; plans are underway to double the amount of irrigated land in Lebanon, with development to be concentrated in south Lebanon, the northern coastal areas and the Bekaa Plain (FAO, year?). Although much of this water is expected to come through retaining winter rains in numerous small dams, there will likely also be increasing pressure on ground water supplies. In the past, farmers tired of waiting for government irrigation schemes often have dug their own wells (FAO, year?), and in the Aammiq region several new boreholes have been dug in the last 2 years (personal observation). At present ground water abstraction is, in practice, unregulated.

Although domestic uses account for a much lower percentage of water use than does agriculture, it is likely that population growth in Bekaa towns and villages will contribute to increasing domestic demand for water resources in the future. It is difficult to find projections for population growth in the Bekaa, but there is a general agreement that the population of Lebanon as a whole is increasing at about 1.8% per year (Lebanese Ministry of Environment, 2003). This does not necessarily apply to the Bekaa; according to the Lebanese Ministry of Environment (2003), rural-to-urban migration will result in net negative population growth in rural areas of –0.18 to –2.2% per year. However, Sarginson *et al.* (1998) estimate that the "effective population" of the Bekaa, which takes into account tourism and other forms of development, will grow by about 50% between 2000 and 2020. Therefore, there is certainly reason to monitor domestic demand for water in the region.

Combining all effects of population growth and increased per capita demand, annual water demand is expected to increase in Lebanon as a whole from 1650 million to 3069 million m^3 between 2000 and 2025, an increase of 86% (El-Fadel and Bou-Zeid, 2001). No data were found for the Bekaa specifically, but given that agriculture will account for about 50% of total water demand in the year 2025, we would expect a significant proportion of the total increase to occur in the Bekaa.

As well as increased demand on water resources, there are also reasons to believe that water and aquatic habitats may become less abundant in future years. First, plans are in place to drain another 1,500 ha of waterlogged lands in the south Bekaa, and to reduce seasonal flooding in another 3,500 ha (FAO, year?). Second, global warming is likely to decrease the amount of available water in the Bekaa. Although most climate change models predict little or no decrease in rainfall for Lebanon (El-Fadel and Bou-Zeid, 2001), an increase in winter temperatures of 0.6-1.3°C and summer temperatures of 0.8-1.8°C would increase the amount of water lost by evapotranspiration, meaning that less water will be available to recharge aquifers. Furthermore, higher temperatures mean that less of the annual precipitation would fall as snow, and the snow that does fall would remain for a shorter period of time. Snow is very important in the hydrological cycle of the Bekaa as it retains water high in the mountains and releases it slowly after the rainy season is over. Thus a decrease in snow means that aquifers would discharge their annual supply of water earlier in the year and become depleted during the dry summer growing season.

The first conclusion from these trends is that water is likely to become less rather than more abundant in the Aammiq region during the next few years, so that a passive approach to the water resources of Aammiq Marsh is likely to result in lower water levels and a shorter flood period in the future. Second, despite growing awareness of the values of wetlands, the number of wetland habitats in the Bekaa may well decrease, thus raising the regional importance of those few that remain.

2. Aims of the present study

In its Management Plan for Aammiq Marsh (2002), A Rocha identified an aim "to maintain, and where possible, enhance the size, functionality and biodiversity of the wetland ecosystem." To achieve this aim, some more specific questions must be answered:

a) Can we increase the water supply to the marsh without conflicting with the needs of local farmers and residents?
b) How much water must be added to the marsh in order to significantly increase the area of the marsh or the length of time it stays flooded?
c) If water is added, which new areas will flood first?
d) Is groundwater pumping in the region affecting the water level and flood duration of the marsh?
e) Is it feasible to create areas of permanent water within the conservation area?
f) Is water quality in the marsh of sufficiently high quality to maintain natural functions and values?

These questions require knowledge of some basic hydrological properties of the marsh system. In particular, we need to know the dimensions (area and depth) of the marsh, quantities of water entering and leaving the marsh through different pathways and the physical properties of the marsh sediments and surrounding lands that determine the subsurface movement of water entering and leaving the marsh.

3. Methods

3.1 Dimensions of the marsh

During 2002, the boundaries of the flooded area were mapped by walking around the marsh and marking the precise latitude and longitude at points along the water's edge using a Global Positioning System (GPS). At the same time, the water level in the marsh was recorded using a gauging board that stood in a deep pool at the western end of the marsh. The GPS survey was repeated at intervals from February to September as the water level declined, thus producing a series of maps that relate the flooded area to water level.

The survey was repeated once in March 2003, during the period of maximum flooding.

3.2 Water budget

From the beginning of the winter rains in 2002 to the onset of winter rains in 2003, as many as possible of the inflows and outflows of water to and from the marsh were quantified. Inflows that were measured included direct rainfall, surface runoff from fields to the south of the marsh, and inflows from the main springs at the western end of the marsh. Direct precipitation was measured using an electronic rain gauge located below

Aana Village. Surface runoff from the fields south of the marsh was measured using a V-notch weir located at the point where this runoff enters the Riachi River (see Figs. 2, 6).

A V-notch weir is a type of dam with a V-shaped gap in the top, over which water can pour (USBR, 2001). Provided the weir is built according to a certain set of conditions, the height of the pool forming behind the weir is proportional to the flux (volume per unit time) of water passing over the weir.

Inflow from the main springs was measured by a rectangular weir, which is larger, but works on the same principle as the V-notch weir. Two rectangular weirs were constructed (see Figs. 2, 7), one beside the broken sluice gates at the end of the short avenue of trees, where all water that merges from the line of springs below Qalaat el Mdiq enters the marsh (weir 2), and another one to capture only flow from the springs at the northern end of the line of springs (weir 1).

Ground water inflow within the marsh area, occurring as springs and/or as seepage from the water table around the marsh, could not be measured directly. However the sum of all unmeasured inflows could be determined as the difference between the total of measured inflows and the total outflow. This value is collectively called “ground water seepage” in the water budget. Although it includes inflow via ditches from fields north of the marsh, which also was not measured directly, this surface runoff is expected to be small compared to ground water seepage.

The only outflows to be measured were surface outflows beneath the bridge near the eastern end of the marsh, and through other small ditches near the bridge that were temporarily opened and closed (see Fig. 2). Because weirs could not be built in this area, water flux (volume per unit time) was calculated by measuring the cross-sectional area of each outlet and the velocity of the water passing through it. Water velocity was measured using a hand-held impeller-type current meter (General Oceanics, model 2030R; Fig. 8).

Other outflows that could be calculated included abstraction by a pump in the middle of the marsh and evapotranspiration. Losses via the pump were calculated as the product of the pumping rate (50L/s for an 8 inch diameter pipe) and the number of hours per day that the pump was operated. Evapotranspiration was calculated by the standardised Penman-Monteith equation, using a Microsoft Excel programme designed by Snyder and Eching (2004), and using temperature and humidity data from 1997 to 2000 at Deir Tahnich, (between Aammiq and Aana Villages, about 3 km south of Aammiq Marsh). Daily evapotranspiration estimates were averaged across the four years.

Ground water losses from the marsh could not be calculated, but could be roughly estimated in 2002 from the rate at which the marsh water level dropped, in relation to the volume of water in the marsh, after all inflows and surface outflows had ceased.

3.3 Hydraulic conductivity of marsh sediments

Hydraulic conductivity (permeability to water) of the marsh sediments was determined by “slug tests.” These involved installing piezometers, or mini-wells, 2 or 6 m deep in the ground, and recording the rate that the water level inside the piezometer recovers after the level is artificially raised or lowered. Hydraulic condutctivity was calculated from the rate of water level recovery using the equations of Bouwer (1978). Slug tests were performed at several locations around the marsh: the seven deep piezometers south of the marsh, and the one shallow piezometer in the Reclaimed area (see Fig. 2). The shallow (2 m) slug test was performed in a 7 cm-diameter open hole dug by a hand-held clay auger. The deep slug tests were performed in 6 m-long, 3/4 inch-diameter steel pipes (piezometers) that were driven into the ground, then lifted 30 cm, leaving the removable steel point of the piezometer in position. The 30 cm gap between the steel point and the piezometer was filled by sand, creating a permeable zone that acts like a piezometer screen.

Additional evidence regarding the permeability of the marsh sediments was obtained by measuring changes of water level in several isolated pools in relation to the marsh. From 25 June to 19 July, 2002, water levels were recorded in 6 small isolated pools (locations shown in Fig. 2) using small poles pushed into the pool sediments to act as gauges.

3.4 Effect of ground water abstraction by water wells

During July and August 2003, fluctuations in the water level of the springs were recorded in relation to the hours that nearby borehole pumps were switched on and off. From 18-19 July, springs water levels were recorded every 2 hours for 24 hours to determine the exact times that daily maximum and minimum levels occurred. Thereafter, measurements were made to coincide with minimum and maximum levels, with additional readings taken at intervals to confirm that water levels were rising or falling as expected.

In January 2004, to determine whether whether ground water flows directly from the Zalqa well (see Fig. 2) to the marsh springs, fluorescein dye was injected into the well. Packets of activated carbon were submerged in the springs to capture the dye, then the presence of dye in these “fluorocapteurs” was detected by dissolving the dye from the carbon and placing the resulting solution in a fluorometer (Universite St. Joseph, Pathology Dept.). Fluorocapteurs were recovered from the springs 1 day, 3 days and 5 days after the tracer was injected, in order to determine the travel time of subsurface water. Because natural water also can fluoresce, one pair of fluorocapteurs (labelled “blank”) was recovered before the tracer was injected in order to measure background levels of fluorescence.

3.5 Water quality

Water quality was monitored simply by taking water samples from the springs, from two other points at intervals along the length of the marsh (one by the Sluice gates and the other near the Irrigation pool; Fig. 2), and from the V-notch weir that drains the fields south of the marsh. Using these points we were able to assess the quality of the main groundwater supply and farmland runoff, as well as the capacity of the marsh to remove excess nutrients. Water samples were sent to the Lebanese Ministry of Public Health for analysis, and on two occasions to Lebanese Agricultural Research Institute (LARI) at Tel Amara. Analysis was limited to major nutrients and basic chemical properties such as pH and total dissolved solids. Pesticides and herbicides could not be measured within the project budget, but it is hoped that they can be included at least once in future tests.

4. Results and discussion

4.1 Marsh dimensions

The area of marsh covered by water at different times of year in 2002, from the maximum water level to dry-out is shown in Fig. 3. In addition, the maximum extent of flooding during the heavy rains in 2003 is shown in Fig. 9. In Tables 1 and 2 below, the area covered by water, and the total perimeter of shoreline in different parts of the marsh is quantified.

Table 1. Flooded area (m^2) in different parts of Aammiq Marsh, from February to September 2002, and maximum extent of flooding in March 2003. The different areas are shown in Fig. 3. Upper marsh includes all areas west of the Sluice Gates, except for the HC pools and reclaimed area. Lower marsh 1 refers to the area between the sluice gates and the Irrigation Pool. Lower marsh 2 refers to the area between the Irrigation Pool and the Marsh Outflow. Lower marsh 3 is the area east of the Marsh Outflow.

Date	Water level (cm)	HC pools	Upper marsh	Re-claimed area	Lower marsh 1	Lower marsh 2	Lower marsh 3	**Total area**
17-23 Feb 02	?	33118	315695	19094	206636	173372	26214	**774129**
28 Feb – 3 Mar 02	~160	38768	385654	79633				**504055**
13 Apr 02[1], 13 May 02[2]	158[1], 170[2]	39887	448062	89811	289667	205443		**1072870**
26-28 Jun 02	146		378692					**378692**
9-15 Jul 02	115[3]	39773	362131					**401904**
23-24 Jul 02	90[3]	39887	346530					**386417**
1-2 Aug 02[4]; 5-7 Aug 02[5]	60[4]; 48-44[5]		282763					**282763**
17-Sep-02	-10[3]		6477					**6477**
4 Mar 03	>202	73689	664396	421648	443343	517563	1067310	**3446366**[6]

[1] upper marsh only; [2] lower marsh only; [3] estimated; [4] south border of marsh only; [5] north border of marsh only; [6] includes 258417 m^2 of land covered in patchy pools.

Table 2. Perimeter of flooded land (shoreline) (m) in different parts of Aammiq Marsh, from February to September 2002, and during maximum extent of flooding in 2003. Parts of the marsh are the same as in Table 1.

Date	Water level	HC pools	Upper marsh	Reclaimed area	Lower marsh 1	Lower marsh 2	Lower marsh 3	**Total perimeter**
17-23 Feb 02	?	1191		583	2618	2228	2566	**16142**
28 Feb – 3 Mar 02	~160	1378	7248	2712				**11338**
13 Apr 02[1], 13 May 02[2]	158[1], 170[2]	1334	5245	2455	2587	1987		**13608**
26-28 Jun 02	146		5951					**5951**
9-15 Jul 02	115[3]	1334	6108					**7442**
23-24 Jul 02	90[3]	1334	6250					**7584**
1-2 Aug 02[4]; 5-7 Aug 02[5]	60[4]; 48-44[5]		5451					**5451**
17-Sep-02	-10[3]		1224					**1224**
4 Mar 03	>202	1652	2071	2806	2509	1584	6302	**19276[6]**

[1]upper marsh only; [2]lower marsh only; [3]estimated; [4]south border of marsh only; [5]north border of marsh only; [6]includes 2352 m of land covered in patchy pools.

Table 1 shows that at maximum water levels during 2002 the flooded area of the marsh (to the marsh outflow defined above) was 107 ha. The area described as the Upper Marsh included a little less than half of this area.

A notable result of the marsh dimensions survey is that the boundaries and area of the upper marsh remained little changed as the water level dropped 80 cm, from 170 cm to 90 cm on the gauge. This shows that though the marsh is located in a very flat plain, the main body of the marsh has fairly steep sides and a well-defined, moderately deep basin. In contrast, the Reclaimed area flooded only shallowly, even at maximum water levels, and dried early as the water level dropped.

4.2 Water budget

The total water budget for the hydrological year October 2002 to October 2003 is shown in Fig. 10 as absolute quantities, and below in Table 3 as percentages of total inflow and outflow. Fig. 11 shows the same components of inflow and outflow as fluxes (volumetric flow rates) versus time throughout the hydrological year. Totals for direct precipitation, evapotranspiration and groundwater inflow were based on an estimated average flooded area of 100 hectares during the 2002-03 hydrological year.

Table 3 Water budget of Aammiq Marsh, autumn 2002-summer 2003, as percentages of total inflow and outflow.

Inflows (m3)			Outflows (m3)		
Springs*	27,906,553	49%	Surface	54,077,984	96%
Riachi	1,138,056	2%	Evapotranspiration	1,353,000	2%
Direct pptn	1,605,000	3%	Pumping	634,392	1%
Groundwater inflow	26,135,279	46%	Groundwater outflow	0	0%

*Flux from North Springs = approximately double the flux from South Springs

The first point to note is that rainfall during this hydrological year was about double the annual average for the Aammiq region (Fig. 12). In fact, precipitation during 2002-2003 was higher than in any year in the last approximately 60 years. Therefore, all values in the water budget, except for the evapotranspiration, pumping and groundwater outflow, are much higher than they would be in an average year. However, we cannot say whether these flows are higher than average by the same factor as the precipitation; they could be more than double or less than double the annual average. We also cannot say whether the various flows have been affected equally by the higher-than-average rainfall, and therefore whether they represent the same proportions of total inflow/outflow as they would in an average year. For the sake of this paper, however, we will assume that they do, at least approximately.

a) Inflows

Qalaat el Mdiq springs – Of particular note in this water budget is that inflow from the springs below Qalaat el-Mdiq represents just 50% of the total inflows to the marsh. It is likely that our estimate of flow from the springs is significantly below the true value; we know that there was considerable seepage beneath the “Short Avenue”, the bank that separates the springs from the main marsh. This is flow that did originate from the springs but was not recorded in the weirs. However, this seepage must be at most only a small proportion of the flux of water flowing over the weirs. Therefore, it appears that there was a significant influx of water from sources within the marsh area. Part of that influx was likely to be seepage of rain water that fell outside the marsh area but reached it via subsurface pathways. This is suggested by Fig. 11, which shows that seepage, the difference between the marsh outflow and the sum of the measured inflows, was much greater during, and shortly after, heavy rain. There was also a component of unexplained influx that remained in the absence of heavy rains, and after the rainy season had finished. This may be partly a constant steady seepage of shallow ground water, but localised upwellings of water, which would appear to originate from a deeper source, also have been observed within the “Reclaimed Area” (Chris Naylor, pers. comm.).

The total flow originating from the springs at Qalaat el Mdiq is less than we might expect based on previous estimates. Haas (1954) gives a figure of 31.5 million m^3 from the Qalaat el Mdiq springs during the 1953-54 hydrological year. It appears that 1953-54 was another heavy rainfall year, but the rainfall of 1650 mm he estimates for the entire catchment of the marsh, including the mountain slopes, is probably less than the 1605 mm recorded on the Bekaa plain in 2002-03. Even if the amount of precipitation was similar in both years, the annual yield from the Qalaat el Mdiq springs has declined by 11.5%, or 3.6 million m^3. This is probably because of the large number of boreholes between Aammiq and Qab Elias that have been built in the last 40 years and now extract large quantities of water for irrigation (see Section 4.4).

Riachi River – The Riachi River collects runoff from the fields south of the marsh, as well as flow from Ain el Abed above Aammiq Village. Overall, inflows from the Riachi were small compared with other sources of water, and smaller than we would expect from the historical records of Haas (1954). According to Haas, Ain el Abed yielded 3 million m^3 during the 1953-54 hydrological year, compared to (much) less than 1 million m^3 during 2002-03. The main reason for this difference is probably that water is abstracted from the spring for irrigation and domestic supply in the villages of Aammiq and Aana. During summer in 2002 and 2003 it appeared that 100% of the Ain el Abed flow was diverted before it could reach the Riachi River. In 1954, Ain el Tine, another spring above Aammiq Village, also supplied water to the marsh, at a rate of 1. 5 million m^3 per year. All of the water from this spring is now used for domestic supply in the local villages. Another reason for the declining contribution from these springs is that the aquifer feeding the spring probably receives less recharge now than it did in 1954. Loss of forest vegetation from the mountain slope in the last 50 years (Walley, 1997) means that rainfall tends to run off directly from the mountainside, rather than being retained to slowly percolate into the subsurface.

b) Outflows

Surface outflow – the total output from Aammiq Marsh in 2002-03 of 54 million m^3 represents a significant proportion of the total flow in the Litani River. The average annual flow of the Litani at Mansoura, just downstream from where the Hafir River joins, is 298 million m^3 (Sene *et al.*, 1999). If double the average annual rainfall in the Litani catchment translated to double the average flow in the Litani River (596 million m^3) in 2002-03, then about 9% of the Litani River flow at Mansoura was derived from Aammiq Marsh.

Evapotranspiration – Evapotranspiration was not a significant component of water loss compared to the loss via surface outflow during the 2002-03 hydrological year (Figs. 10,11). However this was largely because the marsh maintained a through-flow of water throughout the summer. The previous year (summer 2002), which was a more typical year in terms of rainfall, the springs ceased to flow by June 24, and after that the water level in the marsh declined by 1.8 cm per day. Of that decline in water level, about 40%, or 0.69 cm per day, was due to evapotranspiration from the flooded area of the marsh.

Evapotranspiration is much greater during the summer period than during winter and spring (Fig. 13), due to higher temperatures, lower humidity, less cloud cover and stronger winds. This is also the period when inflows to the marsh typically cease. Therefore, although evapotranspiration is never a large component of the annual water budget compared to other pathways of water loss, it becomes significant in lowering the marsh water level once inflows to the marsh have ceased. Also, evapotranspiration is likely to be responsible for a much greater loss of water than is indicated here. The values in Figs. 10, 11 and Table 3 refer only to direct loss from the flooded area of the marsh. However, evapotranspiration from non-irrigated lands surrounding the marsh also will lower the local water table, drawing water out of the marsh. It is likely (though by no means certain) that much of the remaining 60% of the water level decline in summer 2002 was due to this effect.

Pumping – Pumping directly from the "Irrigation pool" in the marsh also was a small component (a little over 1%) of water loss in this year's water budget. However as with evapotranspiration, during an average or dry year, pumping can account for a significant part of the water level decline after inflows to the marsh have ceased. In summer 2002, the single pump in the Irrigation Pool accounted for about 10% of the overall rate of decline, assuming that it was run for 21 hours per day, as in 2003.

Ground water losses – in 2002-03, ground water losses could not be detected because there was always a net gain of water between the springs inflow and the marsh outflow. However, the rate of decline in marsh water level during summer 2002 indicates a rate of water loss via subsurface pathways during an average year. From 24 June to 19 July, 2002, the drop in marsh water level that was not accounted for by evapotranspiration or pumping losses was about 1.1 cm/day, which equals about 0.08 m^3/s if the marsh flooded area (including the upper and lower marshes) was 75 ha at the time. This is roughly equivalent to two 8 inch-diameter pumps running constantly.

4.2.1 Other hydrological properties of Aammiq Marsh

The relationship between rainfall and marsh water level and between rainfall and flux from the springs at Qalaat el Mdiq provide some additional information about the properties of Aammiq Marsh. Figs. 14a and 14b show the relationship between rainfall, marsh water level, and flux from the springs. Rain began in October, though heavy falls did not occur until the beginning of November. The water level in the marsh, however, did not begin to rise for another month, since early rains served only to wet the soils and raise the water table to just beneath the ground surface. The deepest pools in the marsh probably began to rise at about the beginning of December (the water level gauge was not situated in the deepest part of the marsh). The springs at Qalaat el Mdiq filled but did not start pouring water into the marsh until 23 December. Between December 13 and December 20, the marsh water level rose by 1.08 m, during which time there 218 mm of rain fell. Flow from the Riachi River averaged about 0.07 m^3/s, which could account for a maximum of 50 mm rise in water level. Therefore, the marsh water level rose much faster than could be accounted for by the measured inflows. This suggests that the marsh is well connected to the regional water table and receives subsurface runoff of rain water and/or there are other spring sources within the marsh area.

The other important characteristic of Fig. 14 is the short time delay between a rainfall event and an increase in flux from the springs. Typically, flux from the springs would begin to increase within 24 hours of a rain event, and peak within about 48 hours. This shows that ground water flow within the limestone aquifer feeding the springs is very fast, and that at least part of the aquifer recharge occurs fairly close to where the springs discharge.

4.3 Hydraulic conductivity

Hydraulic conductivity of the sediments beneath and around the marsh were estimated informally by recording changes of water level in six isolated pools around the marsh, compared to changes in the marsh itself. Results are presented in Fig. 15. Note that there is no “datum” relating the absolute water level of one pool to that of the others; only the changes over time in each pool should be compared. The rise in water level on May 28 is probably due to closure of the marsh outlet, which occurs every year in summer. Fig. 15 shows that the water levels in all pools rise simultaneously at this time, and thereafter decline at about the same rate. The rate of water level decline between 25 June and 19 July (45-55 cm in 24 days) is much greater than can be explained by direct evaporation from the surface of the pools (maximum of 18 cm over the same period). Therefore, it appears that water is able to flow freely through the sediments underlying the pools and the marsh, and that shallowly the marsh sediments have a very high hydraulic conductivity.

The hydraulic conductivity of the deeper sediments was expected to be lower, as cores of marsh soil showed that below depths of 2-3 m, the sediment was typically a very sticky grey clay. Falling head tests performed in piezometers inserted 6 m into the ground confirmed this expectation. A water level in the piezometers that was raised by about 1 m, declined by only about 1 cm per day. This corresponds to a hydraulic conductivity of about 10^{-5} m/day, which is a very low value, even at the low end of the range for clay.

4.4 Effects of ground water pumping on springs

In mid-July 2004 it was discovered that the water level in the Qalaat el Mdiq springs fluctuates over the course of each day, as pumps in local boreholes are switched on and off. Measurements of these fluctuations, with respect to the hours of pumping in different boreholes (locations shown in Fig. 2) are shown in Fig. 16a. This figure shows that the water level reached a maximum as the four Skaff farm pumps north of the marsh (Saalouk, Zalqa and the two at Tell el Kirdane) were switched on, and a minimum as they were switched off. This indicates that although these boreholes are further from the marsh than those south of the marsh on Hajj Chahine land, they have a greater effect on the marsh water levels. It might be argued that the Hajj Chahine pumps often operated at night as well as during the day and therefore their effect cannot be seen, but typically only one of the three was run after 1 or 2am, yet the water level continued to fall until 6 am when the Skaff farm pumps were switched off. Water levels rose during the day from 6am to 4pm, when only the pumps south of the marsh were running, yet between 4pm and 6pm, when only the pumps north of the marsh were running, the water level began to fall.

Because the Hajj Chahine boreholes were pumped every day, it is hard to determine whether they had some effect on the springs water level or none at all. There is some evidence, however, that the Skaff borehole “Ras en Nabaa,” which also is south of the marsh and very close to the nearest Hajj Chahine borehole, had an effect. Fig. 16b shows that daily minimum water levels (measured at 4pm) did not decline constantly throughout the late summer, but experienced periods of faster and slower decline. Three of the four “plateaux” correspond to times when the Ras en Nabaa pump was not operating. The third plateau also suggests that the effect of individual Skaff farm pumps may be discernible, and the last plateau, which doesn’t correspond to changes in any of the pumps I monitored, suggests that there are other pumps in the region that affect the water supply to the springs. Fig. 16b also suggests that the pump above the marsh at

Saalouk may have had a discernible effect. This pump was operated daily until 2 August, after which it did not run. The rate of decline in the springs from 21 July to Aug 2 was 0.9 cm/day, whereas the rate from 2 to 20 August was 0.7 cm/day. This difference is not statistically significant (1-tailed t-test, unequal variance, n=8, p=0.097), but may be indicative.

From about 3 September, there was a clear slowing in the rate of water level decline in the springs, and then a measurable rise. About this time, one of the Skaff farm pumps was stopped, and the other two were operated only once every two days. There was little change in the regime of the Hajj Chahine pumps. Landowners north of the Skaff property greatly reduced the number of pumps they operated, and the hours of pumping around 25 September. This is after the water began to rise in the springs; however, local farmers can sometimes be a little vague on dates, and it is possible that they began to reduce pumping rates before 25 September. Several local people (Youssef Maroun, Diab Mdawwir, Faisal Halabi) have said that in past years, the Qalaat el Mdiq springs typically begin to refill around the time that pumps in Qab Elias are switched off for the year.

Tracer test – Because one of the three Skaff farm wells (Zalqa; Fig. 2), showed individual influence on the springs, a chemical tracer was injected into the well to see if it would appear in the springs. Levels of the fluorescent tracer detected in the "fluorocapteurs" in the springs are presented in Table 4 below. "Source" refers to the place where springs water actually emerges from the ground. "Pool" refers to the far end of the springs area, where springs water pours into the marsh by weir 1.

Table 4 Results of fluorescein tracer release from Zalqa well: concentrations appearing at two locations in the marsh springs.

	Concentration (µg/L) at source	Concentration (µg/L) in pool
blank	16	8.5
1 day	38	19.5
3 days	35	14
5 days	8.5	25.5

Unfortunately, at the time of the tracer injection, there was a very heavy rainfall, and the flow at the springs reached close to its peak for this year. Possibly as a result of this, the concentrations of tracer recovered in the fluorocapteurs were extremely low, and the technician who analysed the samples warned that with such low values, no conclusions should be drawn. Although we cannot be sure, the pattern of concentration values does suggest that some tracer did emerge at the springs. One day after injection, fluorescence levels at the springs source were double the background level, but returned to below background level by 5 days after the injection. In the pool, where we might expect a tracer to show greater dilution and longer travel time, fluorescence rose above background levels only 5 days after the tracer injection.

Therefore, results suggest that ground water does flow from the Zalqa area north of the marsh directly to the springs, and that travel time over this 2 km distance is less than 24 hours. However, to be certain, a repeat of the tracer test should be done, at a time of lower ground water flows and using a greater number of fluorocapteurs.

4.5 Water quality

The complete results for the water quality survey are presented in Appendix 1, and results for nitrate are summarised in Fig. 17.

a) *Springs* – the physicochemical properties of the springs water give some clues as to the origins of that water. The temperature stayed extremely constant throughout the year, fluctuating by only 0.3°C between January and June 2003, which is probably within the margin of error for the temperature probe. By contrast, water in the Riachi River and in the marsh itself fluctuated by 7.3°C and 8.9°C respectively over the same period. This suggests that the springs water has travelled for considerable distance underground, and includes very little water that has entered locally from the surface. However, from the temperature alone, I cannot estimate how far the water has travelled.

Dissolved oxygen levels, measured in late May 2002, were high at 9.3 mg/L – close to the level that is typical in surface waters. In contrast to the temperature results, this suggests a short subsurface travel time, and also reflects the thin soils of the catchment, since infiltrating water typically loses much of its oxygen as it descends through the soil layer.

A microbiological analysis of the spring water in January 2003 showed >100 *Escherichia coli* and >100 intestinal enterococci per 100 mL. These are definite indicators of contamination by farm runoff or human sewage. Since the mountain catchment has very few animals, the presence of these bacteria suggests water entering either via the farm above the marsh at Saalouk, or further north towards Qab Elias.

Comparison of the water emerging at Ain es Saalouk, 300 m directly above the marsh, and that of the springs below Qalaat el Mdiq in June 2003 (Appendix 1; 19 June) suggests that the two springs have slightly different sources of water. The temperature of the water emerging below Qalaat el Mdiq was 2.4°C higher, pH was 0.5 lower, conductivity (a measure of total dissolved solids) was 80 µS/cm higher, nitrate was 2.8 mg/L higher and potassium was 0.5 mg/L higher. These data suggest that at least part of the water emerging at Qalaat el Mdiq has entered the aquifer at lower altitude, possibly where there is farming, sewage or use of fertiliser. Earlier in the year, nitrate readings in the Qalaat el Mdiq springs reached up to 10 mg/L, also suggesting some contamination.

b) *Marsh* – If Riachi water is typical of water that falls on the Bekaa plain and percolates through the soils, and the springs represents water that has emerged from the deep limestone aquifer, then in theory the origin of water that occurs in the marsh can be determined by comparing marsh water to that of each of these two sources. In January 2003, the pH, nitrate and conductivity of water from the middle of the marsh were midway between the Riachi and the springs. Since flow from the Riachi was only about one tenth of flow form the springs at this time, it would appear that more shallow soil water is entering the marsh besides the Riachi. In March, patterns of pH, conductivity, magnesium and total hardness suggest the same. However, chemical changes to the water can occur within the marsh, so some caution must be exercised in interpreting these results. Furthermore, some parameters of the water, such as chloride, do not confirm this interpretation. Therefore we cannot conclude from the present data that there is a large input of shallow soil water to the marsh.

Freshwater marshes are known to be effective in processing nutrients from inflowing water. Aammiq Marsh received moderately high concentrations of nitrate from the springs and the Riachi River, but was able to remove 30-94% of incoming nitrate within 2.2 km (Fig. 17). Removal rates were higher during summer (up to 94% removal), when aquatic plants were actively growing. The rise in nitrate between the springs and mid-marsh in January is probably because of high concentrations entering from the Riachi and shallow soil seepage.

Phosphorus, another plant nutrient, did not appear to be removed from the water in April 2003. Sulphate, however, appeared to be released in high quantities in all seasons. This is possibly a product of organic matter decomposition within the marsh.

Excavated pool – Although surrounded by intensively managed agricultural fields, the excavated pool was moderately low in nitrate, potassium and total dissolved solids in June 2003. This, as well as high sulphate levels, is probably due to high growth of aquatic plants in the pool.

5. Synthesis – ground water flow to and from Aammiq marsh

Understanding of ground water flows in the Aammiq region is hampered by a lack of detailed geological knowledge, particularly beneath the Bekaa Plain. However, the evidence described above, as well as some other interesting behaviours of ground water near the marsh, can help us develop a tentative model for the area.

Clearly most ground water in the area originates in the Barouk mountains to the west of the plain, and flows downslope from west to east. When this ground water reaches the valley floor, the picture becomes less certain. The fact that boreholes north of the marsh have a definite effect on the Qalaat el Mdiq springs, whereas those south of the marsh do not strongly suggests that at the foot of the mountains, ground water has a strong north-to-south component to its flow.

While most boreholes in the region are located at the foot of the mountain and draw most of their water from the limestone, two by Houch Aammiq (each 70 m deep) and another two east of the Skaff farm (80 and 100 m deep respectively) draw a reasonable flow of water from the sediments of the plain. This shows that at least some of the sediment layers beneath the plain are moderately permeable to ground water flow, and therefore that the ground water at the foot of Barouk likely also has an west-to-east component to its flow.

Because of the strong effect of ground water pumping north of the marsh, I would suggest that at the foot of Barouk, ground water is flowing more strongly along the edge of the plain (NNE-SSW) than across it. This would be expected if the limestone aquifer has higher hydraulic conductivity than the sediments of the plain, because the limestone is shallow only close to the western boundary of the plain. Also, the fault line that runs NNE-SSW below Qalaat el Mdiq may be acting as a conduit to increase the ground water flow in this direction.

On the Bekaa plain the shallow sediments (from about 2 m to more than 6 m deep) appear to be quite impermeable to water, and “confine” the aquifer beneath. Evidence for this is not only the results of slug tests (described above), but also the fact that the two Skaff farm wells on the plain and the two wells at Houch Aammiq can be strongly artesian during the rainy season. Another piece of evidence is that a shallow hand-dug well located less than 100 m from the two deep Skaff farm boreholes maintains a constant water level throughout the summer regardless of the amount of water withdrawn by those boreholes (in striking contrast, a pool located beside the Houch wells dries out almost immediately that pumping begins in those wells, but this could be due to leakage around the sides of the borehole shafts rather than through the sediments).

If indeed the aquifer at the foot of Barouk is confined by impermeable shallow sediments of the plain, then the limestone outcropping of Qalaat el Mdiq, by pushing through these sediments, probably provides a conduit to the surface. This would explain why springs occur at Qalaat el Mdiq, but not at all points along the foot of the mountains.

Above the impermeable layers of sediment in the plain, there appears to be a thin layer (maybe about 2 m thick) of very permeable surface sediment. Slug tests in these sediments, observations that water levels in isolated pools rise and fall simultaneously with the marsh, and the apparently large volume of ground water seepage in the water budget show that the marsh is well connected hydrologically to the regional water table. This implies that there are probably two water tables in the Aammiq region – one beneath the impermeable sediment layers and another “perched” on top of it. It appears that Aammiq Marsh is well connected to the perched water table, but connection to the deeper aquifer probably occurs only at the Qalaat el Mdiq springs.

If this model is correct, then there are implications for water management in the area. For example, irrigation on fields surrounding the marsh may in fact maintain water levels in the marsh by feeding the local water table, or at least reducing the amount of water lost from the water table by evapotranspiration. This depends, of course, on how much of the irrigation water reaches the water table. It also depends on where this water has been brought from; if it were ground water extracted from north of the marsh, the benefit of adding water to the shallow water table probably would be outweighed by the loss of water from the springs.

Conclusions and recommendations

The hydrology of Aammiq Marsh is currently not well understood due to a lack of geological knowledge and the fact that long-term monitoring of water levels has not yet been undertaken. The current study aims to provide baseline data on which future monitoring of Aammiq Marsh can be based. The hydrological year during which most of the data in this study was collected was, unfortunately, untypical in having very high rainfall. However, the data can still be used with caution provided this in kept in mind.

Using the data presented here, we can give at least partial answers to the questions listed in Section 2. Historical observations over the last 30 years and observations of water level fluctuations during summer 2003 show that groundwater pumping in the region is definitely affecting the water supply to the springs below Qalaat el Mdiq, reducing marsh water levels and the duration of the wet period. However, it appears from our limited data that the main effect is from pumps north of the marsh, and that those to the south have little impact. Therefore, efforts to change water management in the region for the benefit of Aammiq Marsh should concentrate on reducing groundwater use north of the marsh. It is likely that groundwater pumping as far away as Qab Elias affects the water supply at Aammiq, and therefore management strategies should be applied at a regional rather than a local scale. In order to benefit Aammiq Marsh, the main aim of water management in the region should be to reduce extraction of groundwater from the limestone aquifer along the western edge of the Bekaa Valley. Extraction of groundwater from the sedimentary deposits in the middle of the valley may also have a serious effect on water levels in Aammiq Marsh. At the time of writing there are very few such boreholes, but two are now ready for operation, and monitoring their effect on Aammiq Marsh is strongly recommended. Withdrawal of water directly from the marsh of course also lowers marsh water levels, and water management should aim to reduce or end this practice if possible.

It is possible to reduce groundwater usage in the region while maintaining sufficient water for agricultural needs, but such changes are likely to be expensive. Improvements to existing irrigation networks, including fixing leaks and delivering water via pipes rather than open ditches would reduce water loss before water is applied to the crops. More efficient technologies such as drip irrigation could further reduce evaporation losses once the water is applied. All of these solutions are expensive, however, and the weak state of the agricultural economy in the Bekaa currently make them beyond the reach of most farmers.

The data and observations recorded in 2003 also give some indication of how much water must be added to the marsh to increase the duration of the wet period. Because the outflow of the marsh is usually blocked during the summer, only a moderate flow of water from the springs is sufficient to balance pumping, seepage and evaporation losses and maintain surface water in the marsh. During July 2003, this was approximately 0.8 m^3 per second, including inflow from the springs and from seepage.

In order to increase the flooded area during the wet season, the best strategy is not to add more water, since there is an abundance at this time of year, but rather to reduce the rate of outflow from the marsh. This could be achieved by partially blocking the marsh outflow at the “Sluice Gates” in the middle of the marsh or at the “Marsh Outflow Measuring Point” (see Fig. 2 for locations). Maps of the spring flooding in March 2003 show which areas would be the first to flood if blockages were made such that the marsh water level rose above 202 cm on the main staff gauge. Clearly the only areas affected would be west of the blockage point. Reducing the outflow from the Sluice Gates would have the advantage that, if done in a controlled way, no land presently in production would be at risk of flooding. The additional flooded area would all be within what is now termed the “conservation area”. However, because flow to the Lower Marsh would be reduced, the flooded area east of the Sluice Gates may decrease slightly. For ecological benefit, a better point to reduce the outflow would be at the Bridge (“Marsh Outflow Measuring Point”), which is much further to the east. However, this is likely to cause flooding of some low-lying agricultural fields north of the marsh, and may be impossible for that reason.

The data recorded in 2002, an average rainfall year, suggest that it would not be difficult to create areas of permanent water within the marsh. During that year the water table in the marsh dropped only 1-2 metres below much of the marsh, and in fact some deep pools and ditches remained wet throughout the summer. Therefore more pools that remain wet throughout a normal-rainfall year could be created by excavating. However, to create pools that retain water above the level of the surrounding water table would require lining the pools with clay or a plastic liner. The shallow sediments beneath the marsh and surrounding lands are so permeable that water added to a raised pool would be quickly lost by ground seepage.

In terms of water quality, Aammiq Marsh appears to have no serious problems at present, although this conclusion is pending thorough examination of pesticide levels. The analyses in this report, however, caution against complacency. While it may appear that the water supply for Aammiq Marsh comes from an undisturbed mountain catchment, the levels of nitrogen and faecal bacteria suggest that human-derived contaminants are able to enter the groundwater before it reaches the marsh. Therefore, there remains a possibility of ecologically-damaging nutrient levels, as well as diseases and toxic chemicals entering the marsh water supply. Ongoing monitoring is recommended.

In summary, in the author’s opinion the water supply to Aammiq Marsh is under serious threat, and water across the entire Aammiq region must be managed carefully and efficiently if in future the marsh is to maintain sufficient water levels to support wildlife and essential ecological processes during the long annual dry period. It is recommended that a critical next step in the management of water resources at Aammiq is to identify minimum flows, and minimum water levels that will sustain wildlife and ecological processes at different times of year.

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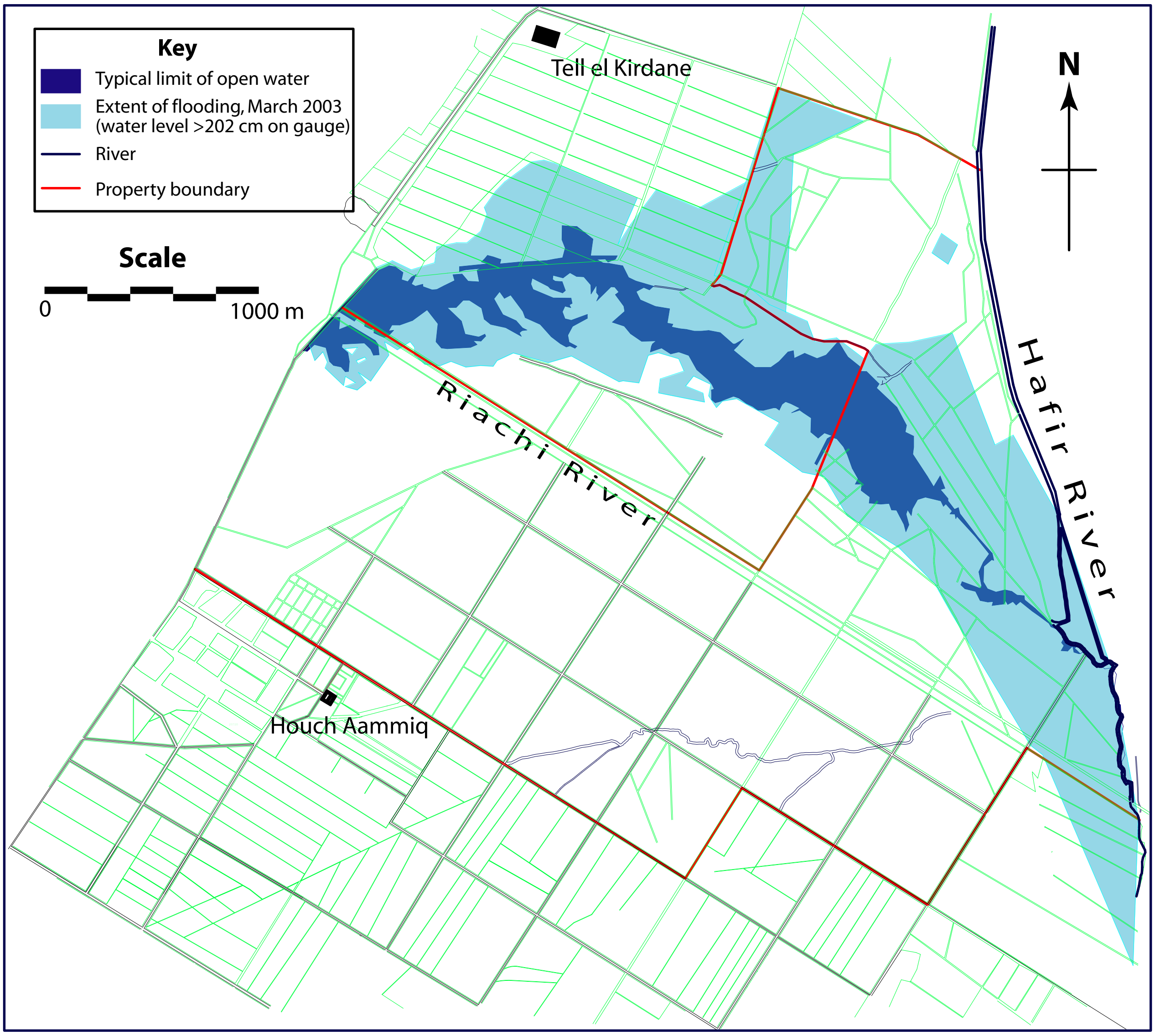

Fig. 9 Maximum extent of flooding during spring 2003. Also shown is the marsh boundary at average water levels during winter.

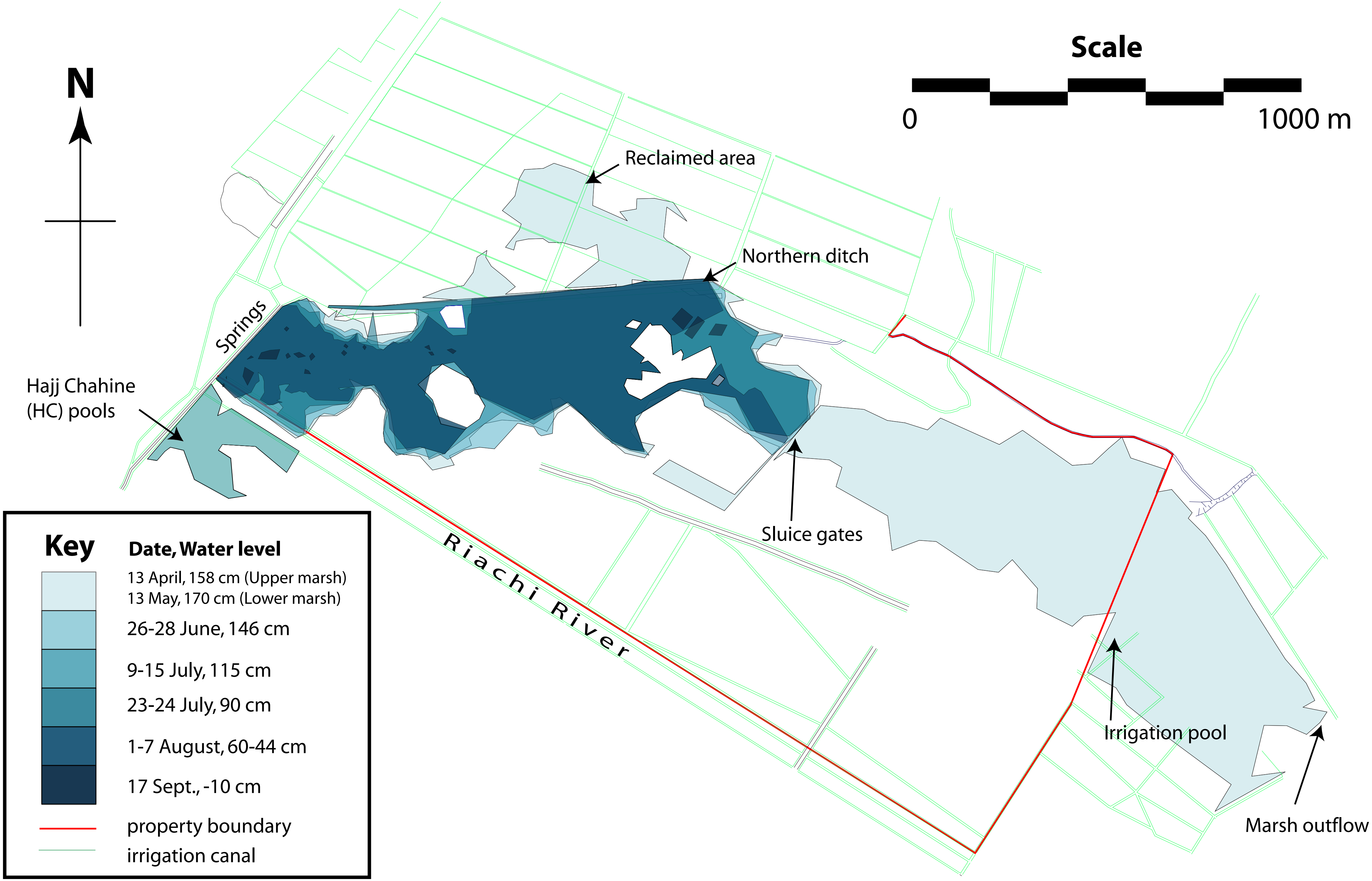

Fig. 3 Boundaries of flooded area as water level declined between spring and summer, 2002. Widest boundary shown is the maximum extent of flooding in 2002. Note that the Lower Marsh was only surveyed on 13 May.

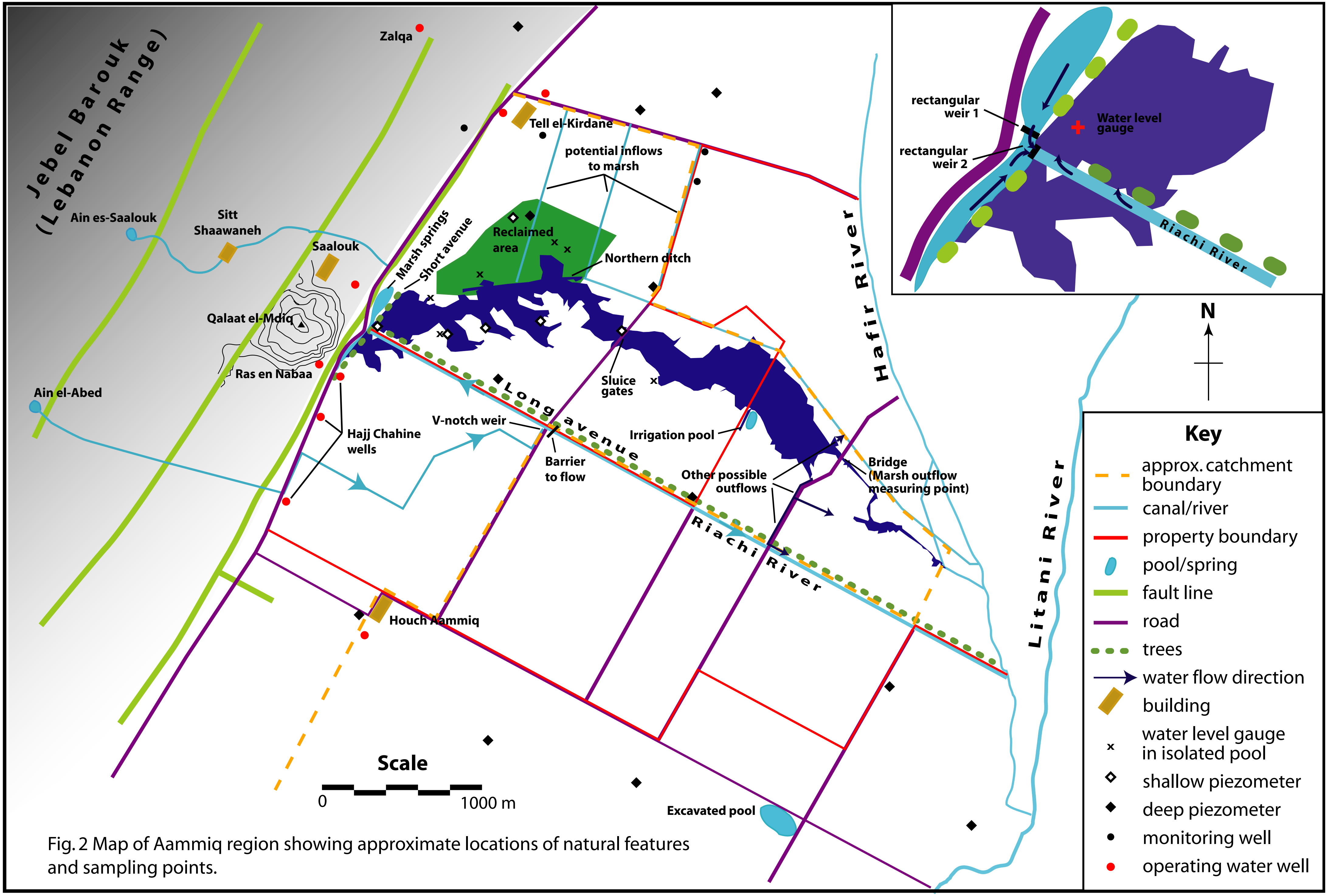

Fig. 2 Map of Aammiq region showing approximate locations of natural features and sampling points.

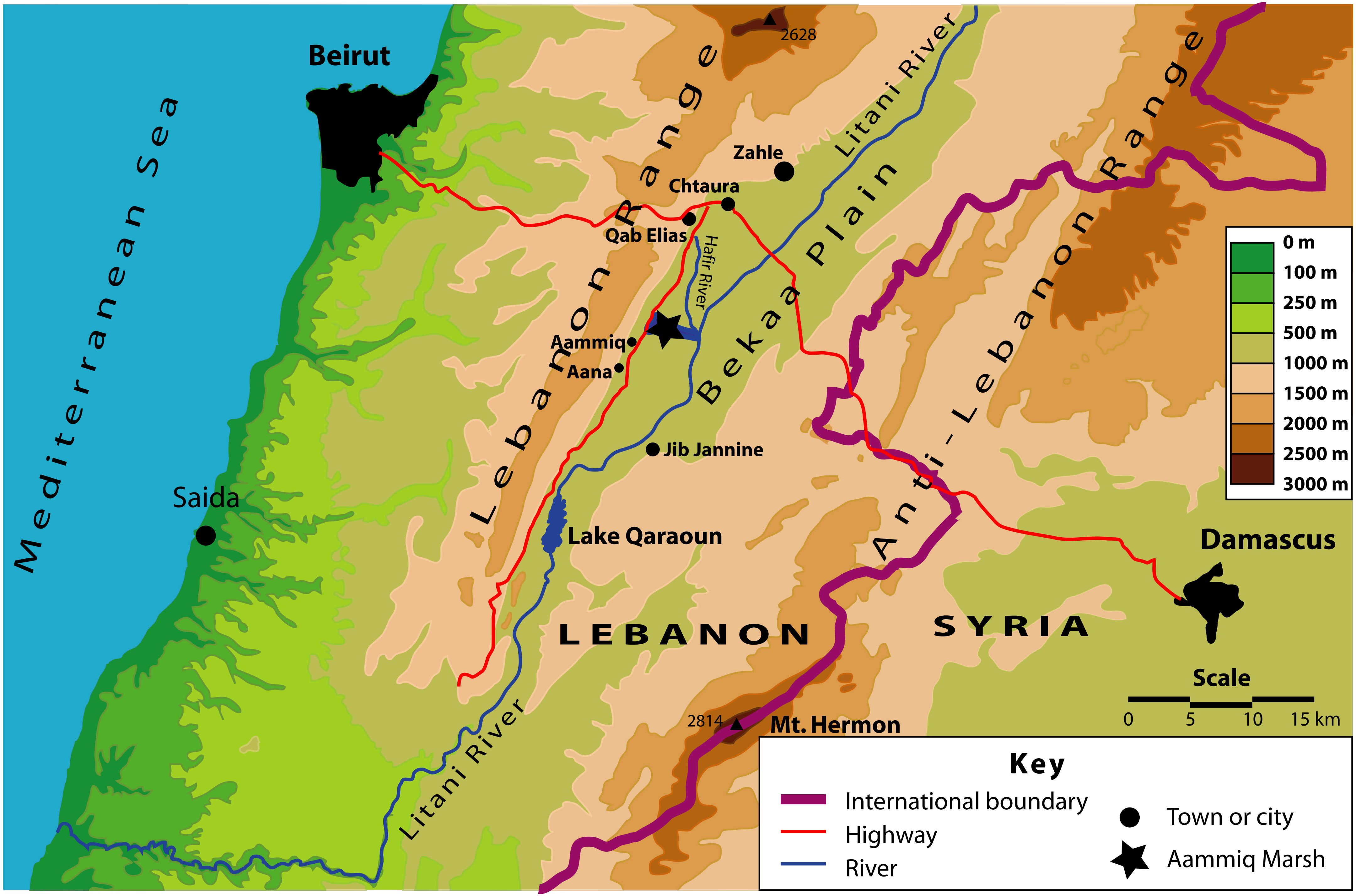

Fig. 1 Topographic map of central Lebanon. (Used with permission of GEOprojects (U.K.) Ltd.

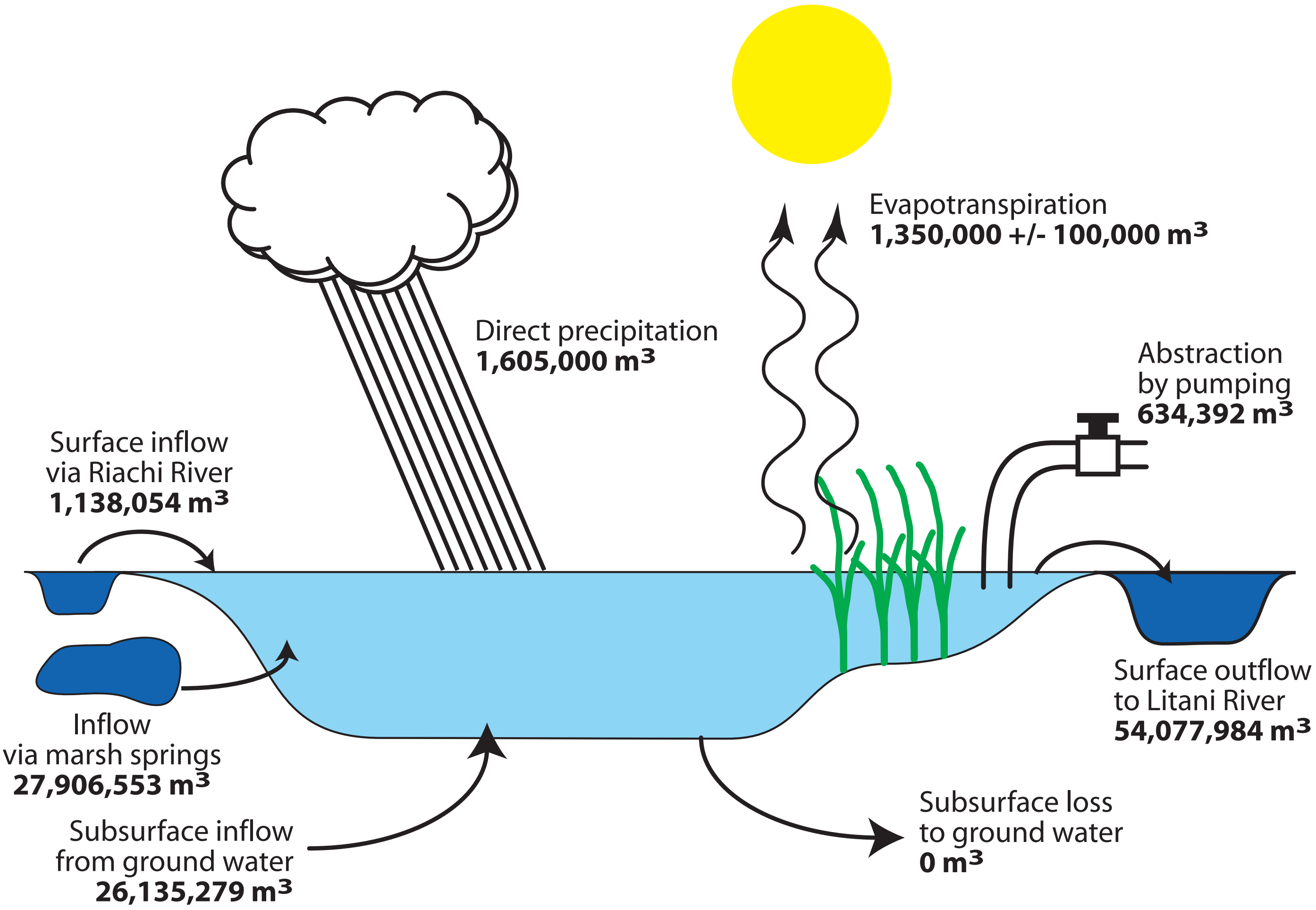

Fig. 10 Water budget for Aammiq Marsh, autumn 2002 to summer 2003