

## Groundwater Flow Connections in Palestine Shared Aquifers revisited

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### ABSTRACT

The research in this paper breaks with the conventional wisdom on the hydrogeology of some of the possibly most studied and documented aquifers in the world – those that underlie Palestine (oPt) and Israel.

Rather than the three transboundary aquifers (2 Mountain, 1 Coastal) so commonly referred to, it is shown that actually all aquifer basins and aquifers in historical Palestine are shared and transboundary.

The sustainability, methodology and political implications of this research reach broadly and deep: The research calls into question the common methodology applied to describe and define the aquifers, their individual recharge and discharge mechanisms, their boundaries and flow connections to adjacent basins and aquifer stockworks. This enhanced understanding will help in addressing the lack of understanding of and in re-focussing on the crucial question of transboundary and inter-basin aquifer flow connections.

The implications for the Palestinian-Israeli water conflict, furthermore, are just as significant. The research sets the scientific foundation for a fundamental re-negotiation of the inequitable distribution reached in 1995, thus adding a hydrogeological dimension to those of justice and law claimed by a growing number of Palestinians.

**Key words:** transboundary aquifer, flow connection, recharge, equitable and reasonable share, oPt

### 1. INTRODUCTION – THE INTERNATIONAL “LAW OF TRANSBOUNDARY AQUIFERS”

Articles 2a of the draft Law of transboundary aquifers (UN-General Assembly, A/63/124) defines an “aquifer” as “a permeable water bearing geological formation underlain by a less permeable layer<sup>1</sup> and the water contained in the saturated zone of the formation“. An “aquifer system” is a “series of two or more aquifers that are hydraulically connected” (2b). In other words, for the formational continuity, an aquifer has to cross a border and for a hydraulic connection, groundwater has to flow across a border. Article 2 (f) of the law defines a “recharge zone” as “an aquifer that receives a non-negligible amount of contemporary water recharge”<sup>2</sup>. Despite the weaknesses<sup>3</sup> and vagueness of the draft, this paper tries to apply both aquifer definitions<sup>4</sup> (Art. 2a, b) as well as the recharge definition (Art. 2f) to all aquifer basins in Historical Palestine, in line with the draft law<sup>5</sup>. At its centre stands the question: Which basins of Historical Palestine are shared and to what extent?

<sup>1</sup> The draft fails to quantify how much less permeable a layer should be to qualify as bottom of aquifer – several orders of magnitude in k-value? This becomes a problem for application when dealing with leaky aquifers, in-homogenous stratified aquifers with a series of aquitards, aquifers and perched local aquifer horizons.

<sup>2</sup> The draft fails to define and quantify the term ‘non-negligible’ any further, but the question here is: How much would be a “negligible amount” of flow? Certainly, 50% or even 30% of total flows are more than enough to qualify for a non-negligible contribution. But is a negligible portion closer to 5%, 10% or 20% of total flows?

<sup>3</sup> Also the principle of “*Sovereignty of aquifer States*” (Art. 3) poses a problem for the equitable and reasonable utilization of shared aquifers and breaks with the logic of the UN Convention on Surface Water courses. Applied to surface water, it would allow any upstream riparian to fully dry out a river. All basins where Palestinians are upstream (WAB, EMB) would leave Israel without access to water, if Palestinians were to exploit “sovereignty” to the fullest. Full sovereignty and sharing are mutually exclusive.

<sup>4</sup> Yet, the definitions can be mutually exclusive: Flow connections can exist without formation continuity.

<sup>5</sup> Unlike Israel, the official Palestinian line actively endorses and promotes international law. It seeks water negotiations for a “just solution based on international law” (PWA 2010; Phillips et al. 2004). Palestinians also endorse all 9 factors (a-i) *relevant to equitable and reasonable utilization*, as drafted in Article 5, as well as the *obligation not to cause significant harm* (Art.6), *to cooperate* (Art.7), *to exchange data and information* (Art.8) and to *protect, preserve and manage* the resources in a responsible and sustainable manner (Part Three).

## 2. THE CONVENTIONAL VIEW ON OF AQUIFERS IN HISTORICAL PALESTINE

Common literature differentiates seven basins in Historical Palestine (EXACT, 1998, SUSMAQ, 2002, HSI, 2006, Fig. 1): The Negev, the Galilee, Lake Tiberias and Mount Carmel, as well as the Coastal Aquifer and the two<sup>6</sup> Mountain aquifer basins. Figure 2 shows the rather confusing amount of aquifer stockworks overlaying each other according to the grouping system of the Hydrological Service of Israel (HSI): Along the coast stretches the **Coastal aquifer** (CAB) from Gaza to Mt. Carmel (pink, purple). At **Mount Carmel** (MCB) a shallow thin strip of Carmel coast aquifer is overlying the Cenomanian aquifers (rosé). Further north, the **Western Galilee** (WGB) again consists of deeper aquifers (Upper Albian-Cenomanian-Turonian Mt. Aquifer) and shallower more localized aquifers (Eocene, Neogene and Pleistocene) in light green colour. In the Northeast, **Lake Tiberias basin** (LTB) includes all aquifer stockworks from Jurassic (in the annexed Golan) to Cenomanian, Eocene and Neogene (strong blue). South of Lake Tiberias and the Western Galilee follow the Eastern Mountain Basins (EMB) (yellow colour). Regionally they consist of the West Bank aquifers (Eastern and North-Eastern Basins), shallower units like the Eocene and the alluvial Jordan Valley aquifers. North of the West Bank, this agglomerate of interconnected basins also includes the Nazareth Mountains and the Wadi Harod basins. Between the Eastern Mountains and the Coastal plain stretches the **Western Aquifer basin** (WAB) – consisting only of Upper Albian-Turonian carbonates (light blue). In the South, three stockworks of aquifers build up the series of **Negev and Araba Basins** (NAB) (strong green), with a lower system of very deep aquifers (Neocomian-Aptian), an intermediate system (Cenomanian/Turonian) and an upper system of Eocene to Quaternary series. Only some very minor units of local aquifers with a negligible total pumpage are not included in this system.

## 3. THE THREE SHARED AQUIFERS, ACCORDING TO THE CONVENTIONAL VIEW

According to conventional wisdom only 3 of the aquifers are transboundary or shared: The Mountain Aquifers (WAB, EMB) and the Coastal Aquifer (CAB). It is important to stress that such common mistakes frequent in the literature are due to a conceptual misunderstanding according to which these aquifers are considered discreet, independent and unconnected basins, laterally isolated from each other. Such an example is shown in figure 1 (EXACT aquifer map, 1998). The considerable vertical overlay of most basins (Fig. 2) is neglected. If only all major aquifer stockworks overlaying each other are counted, their combined area stands at 56.390 km<sup>2</sup><sup>7</sup>, about double the size of the entire country. Aquifer and basin overlay is the rule, not the exception.

It should be stressed that recently, Israel has begun to pretend that the Coastal Aquifer was an unshared basin located exclusively inside Israel (1949 borders)<sup>8</sup>. Only the Mountain aquifer basins, where Palestinians sit upstream, are shared transboundary flow and aquifer systems, Israel insists<sup>9</sup>. The Western Aquifer (WAB) is a classically shared aquifer with over 85% of recharge in the West Bank (upstream), but extractions almost exclusively (94%) controlled by the downstream riparian, Israel in the coastal plain. The North-Eastern Basin (part of EMB) is similarly inequitably shared, with Israel enjoying control over 113mcm/yr (80%) of outflows<sup>10</sup>.

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<sup>6</sup> Many authors differentiate 3 Mountain aquifers – Western (WAB), Eastern (EAB) and North-Eastern (NEAB) Aquifer Basin, while the Hydrological Service of Israel (HSI, 2006, 2008) lumps EAB and NEAB together into a common aquifer system, called Eastern Mountain Basins (EMB). Hydrogeologically, both approaches are valid. This paper will follow the HSI-system for reasons of overview and comparable data for all basins.

<sup>7</sup> Aquifer sizes according to HSI, 2006 & 2008, to SUSMAQ, 2004 and Gvirtzman, 2002

<sup>8</sup> While older maps (Gvirtzman, 2002) include Gaza in the CAB, more recent Israeli maps (HSI, 2006, 2008) 'elegantly' let the CAB end at the doorstep of Gaza – a transparent attempt to avoid Israel's obligation to furnish Palestinians with an equitable share of this powerful aquifer. According to Vengosh et al. (2005) Gaza obtains 37mcm/yr of lateral groundwater inflow from Israel (~80% of the amount of rainfall recharge in Gaza).

<sup>9</sup> This is a tactical, not scientific position – only where Israel sits downstream, its wants the water shared.

<sup>10</sup> In both basins, Israeli military rule and wanton discrimination prevents Palestinians from developing their equitable share (World Bank, 2009; Messerschmid, 2007)

On the other hand, the Eastern Aquifer within the EMB is almost exclusively restricted to the West Bank with only *negligible* cross-border flows (Ein Gedi springs - 2.46mcm/yr and Arad cell<sup>11</sup> inflows <0.89mcm/yr, together 1.7% of total aquifer flows)<sup>12</sup>. Yet, Israel insists that the EAB be treated as a shared transboundary basin. In the Oslo-II agreements Israel’s position to demand continued control and utilization of the lion share in this aquifer (155mcm/yr or 79% of all flow<sup>13</sup>) is based on the alleged nature as a “*shared aquifer*”, despite <2% of cross-border flows.



Fig. 1 Allegedly adjacent aquifers (EXACT, 1998)

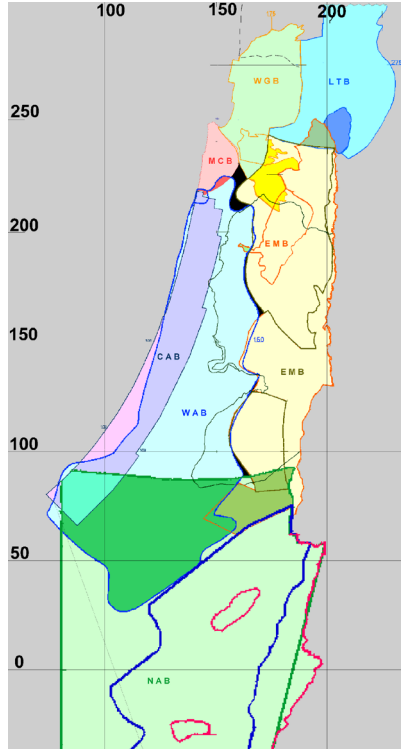


Fig. 2 All aquifers overlying each other (modified after HSI, 2008)

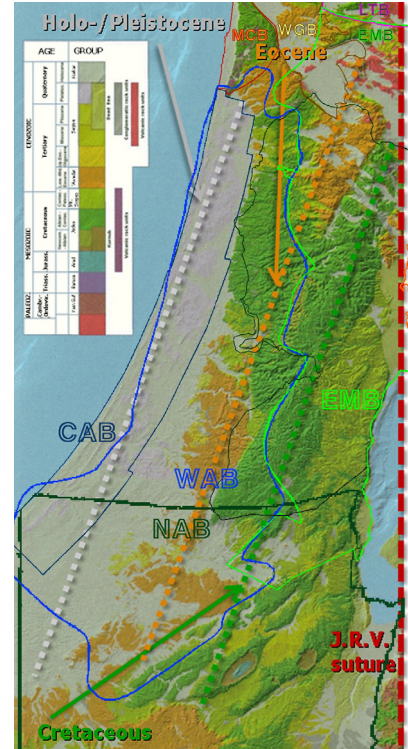


Fig. 3: Geological relief map and HSI-basins (modified after GSI, 2002)

#### 4. THE AQUIFERS CONVENTIONALLY CONSIDERED TO BE UNSHARED

What about the other basins – NAB, MCB, WGB and LTB; which of them are shared according to the definitions of the draft, i.e. by the extent of formations (4.1) and hydraulic connections (4.2)?

##### 4.1. Formation extent

Geographically, two of the four allegedly ‘unshared’ basins lap into the oPt (Fig. 2), NAB and WGB into the West Bank, NAB also into Gaza. Only MCB and LTB formations lie exclusively inside Israel. As the relief map (Fig. 3) shows, the land area of Historical Palestine can be divided into three major SSW-NNE trending aquifer stockworks, from sub-recent alluvial (grey), to shallow Eocene (orange) and deep Cretaceous (green), built up by one continuous geological realm, the Cretaceous-Tertiary sedimentary basin along the old continental hinge line – one uninterrupted outcrop (and subcrop) from the Negev up to the Galilee. Structurally it is an integral part of the Syrian Arc system. It turns out that the only mechanism that effectively inhibits any flow connections are deep graben structures, such as the Jordan Rift Valley or Wadi Fari’a (separating EAB from the so-called NE-tip).

<sup>11</sup> southernmost cell (No.667), no rain recharge; only inflows from EAB (North) & NAB (South); HIS (2006).

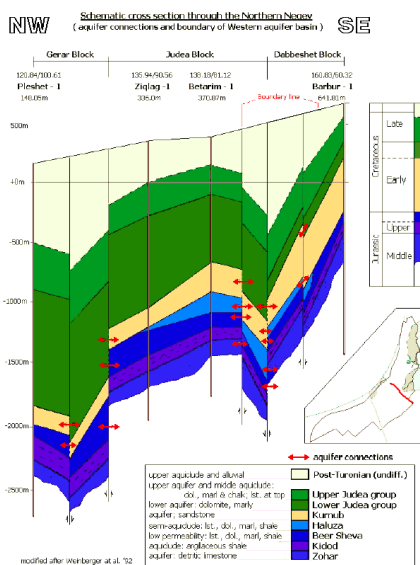
<sup>12</sup> If any basin in Historical Palestine has negligible transboundary flows, then the EAB, this paper tries to show.

<sup>13</sup> Eastern Mt. Aquifer average (‘98-‘07) after HSI (2008), including the powerful Dead Sea springs

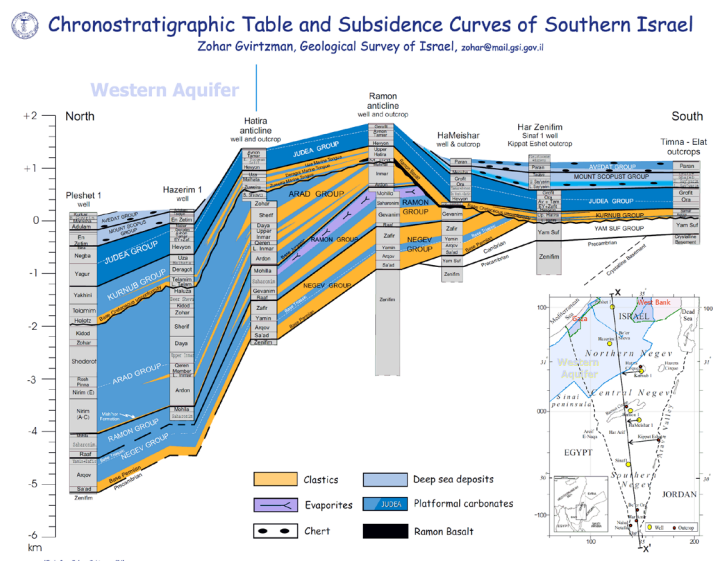
#### 4.2. Flow connections

In line with Art. 2b & f, all basins are *hydraulically connected*, exchanging transboundary groundwater flows and sharing zones with common *contemporary recharge*. They constitute common transboundary *aquifer systems*. CAB, WAB and EMB usually are seen as shared. The same will now be shown for NAB, MCB, WGB and LTB.

**Negev and Araba Basins (NAB):** Weinberger *et al.* (1994) report: "One of the main processes of Judea Group in the northern Negev is *continuing intrusion* into the aquifer. It appears that the Judea Group *sub-aquifers are locally interconnected*. These sub-aquifers, are juxtaposed, as a result of faulting" (Fig. 4). Deep faults enable large flow connections and groundwater exchanges between Judea group (Mt. Aquifer), deep Kurnub, Jurassic and Eocene. The Eocene in turn is connected to the Pleistocene. In North-South direction, Judea group (Mt. aquifer) is one continuous aquifer reaching from the WAB into the NAB (Fig. 5) The deeper Kurnub sandstone aquifer below drains from a structural high in the North-Central Sinai in NE directions towards the Dead Sea (Vengosh, 2007).



**Fig. 4: Aquifer connections in the Negev (NW-SE trending cross-section)**



**Fig. 5: Continuation of the Western Mountain Aquifer from the Coastal Plain to 'Aqaba (N-S trending cross-section)**

The main Cenomanian aquifer is partly fed from WAB and EAB in the West Bank. All major aquifer stockworks in the NAB, from shallow to deep are hydraulically connected (Art. 2 b). The Cenomanian and deep aquifers in the South assemble to a common 'aquifer system' (Art 2 b) with 'non-negligible' amounts of flow exchange.<sup>14</sup>

**Mt Carmel Basin (MCB)** consists of a Pleistocene coastal aquifer cell (#410<sup>15</sup>) and 2 deep carbonate Mt. aquifer cells (# 420, 421). HSI (2008) sets the boundary between WAB and CMB at the southern foothills of Mt. Carmel, whereas Dafny *et al.* (2010) locate the boundary inside the Mt. Carmel mountain range. The boundary between MCB and WAB has to be assumed a flow boundary. The pump regime strongly affects flow amounts and directions.<sup>16</sup> Dafny *et al.* (2010) indicate southern flow directions, from Mt Carmel towards the WAB plains and Taninim springs. Accordingly, the two basins act as "recharging aquifer" and "discharge zone"<sup>17</sup>, respectively, as defined in Article 2 (f) and (h). Taninim (Timsah in Arabic) springs are the main artesian outlet of the WAB today with

<sup>14</sup> 5% of WAB's annual yield (20mcm) draining the Negev would equal 30% of all NAB recharge ~60mcm/yr.

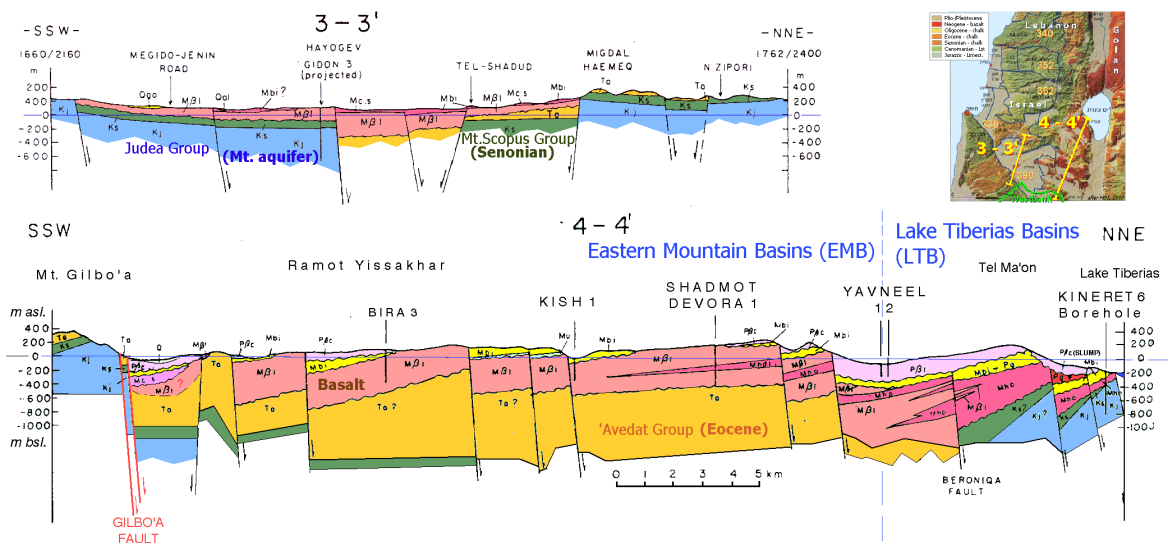
<sup>15</sup> HSI (2008) uses a numbering system to divide the basins into aquifers, cell groups, cells and sub-cells.

<sup>16</sup> In half a year alone (Apr-Sep '07), water levels in the northern-most WAB dropped by 2.5m (HSI, 2008)

<sup>17</sup> At least under the current abstraction regime, in which Israel massively over-pumps the Western Basin, in breach of the Oslo-II agreements. Flow directions under undisturbed conditions may have been reverse.

20-58mcm/yr (historically ~70mcm/yr), certainly not a 'negligible' amount of flow<sup>18</sup>. Deep faults connect the Mountain Aquifer to the Pleistocene aquifers and the springs emerge from the shallow Pleistocene gravels, mostly in the MCB (cell 410), but partly also in the CAB. The rising groundwater of WAB mixes with CAB and MCB flows before the springs discharge at surface. Taninim springs constitute a common 'discharge zone' (Art. 2 h). At Taninim springs, the three basins – WAB, CAB and MCB thus constitute a common 'aquifer system' (Art. 2 b).

**Western Galilee and Lake Tiberias Basins:** Lithologically and structurally, the Cenomanian Mountain aquifers of the North (WGB, LTB) and the West Bank form one formation, with strong faulting<sup>19</sup> and frequent lateral facies changes (Rosenfeld & Hirsch, 2005). As in the Negev, this leads to flow connections between the deeper aquifer stockworks (Cenomanian, Lower Cretaceous and maybe Jurassic) but also between the Judea Mountain aquifer and the Eocene. For the Cenomanian Mountain aquifer, a flow direction from the West Bank towards the Galilee is more likely (according to water level contour maps by HSI, 2006, 2008). Conversely, the Lower Cretaceous aquifer flows N-S with recharge in the North (outcrops with rain up to 950mm/yr in Lebanon and along Israel's Northern border). The shallow Coastal Aquifers most likely are hydraulically disconnected from the deeper basins in the hinterland. They are assumed here as non-shared sub-basins. The Neogene Aquifer of the Western Galilee Basins reaches into the West Bank where it is recharged (non-negligible flows). The Eocene basins of the West Bank (Nablus syncline) and of the Western Galilee (cross-section 3-3', Fig. 6a) are *structurally* discontinuous. However, near Hayogev and near Migdal Ha-Emeq, the Eocene (T<sub>a</sub>, yellow) is juxtaposed against the Cenomanian-Turonian (Judea group, K<sub>j</sub>, blue). Therefore *direct flow* connections between the aquifer stockworks are enabled.



**Fig. 6a, b:** SSW-NNE cross-sections from EMB to WGB (4-4') and to LTB (3-3')  
 note: LTB and EMB Cenomanian aquifers are one uninterrupted lithostratigraphic layer...

Fig. 2 (top right) shows an almost arbitrary Upper Cenomanian boundary between EMB and LTB in Yavne'el area (Fig. 6b), 6km WSW Lake Tiberias. No surprise, the Cenomanian of the Galilee and LTB is hydraulically connected: Lake Tiberias basins receive some 125mcm/yr of groundwater flow from the Eastern Galilee (Gvirtzman, 2002; HSI, 2006). The shallow Neogene basins of EMB along the JRV overlap with LTB and reach up right to the coast of Lake Tiberias (Fig. 2). The Eocene aquifer is isolated by erosion, but with stockwork connections along deep faults (Fig. 6a).

<sup>18</sup> All Palestinian controlled wells and springs in the West Bank currently yield 81mcm/yr (estimates for the year 2010; unpublished correspondence with Dr. S. Attili, Head of PWA; July, 2010).

<sup>19</sup> Gilbo'a faults (Fig. 6b) at the N edge of the West Bank have a combined vertical throw of well over 1000m. Other faults vertically throw between 200m and 600m.

All basins (bar the shallow Galilee coastal aquifer) and aquifer stockworks of the Western Galilee are hydraulically connected to the West Bank aquifers. Due to deep faulting they are likely to form one interconnected ‘transboundary aquifer system’ (Art. 2 b, c). The Cenomanian (Judea Group) and Neogene aquifers of LTB are in contact – both, as formation and hydraulically, with the EMB basins emerging from the West Bank. Eocene and Cenomanian, locally, form a combined ‘aquifer system’.

## 5. RESULTS

Both definitions of Art 2 b, c - formational, lithostratigraphic continuity (A) and hydraulic flow connections - were applied to evaluate the transboundary nature of all aquifers, particularly those commonly considered unshared.

**A) Formation continuity** can be evaluated by basin and by aquifer layer: By basin: Only CMB and LTB lie entirely outside the West Bank. By aquifer formation: The Cenomanian (Upper Albian – Turonian) Mountain aquifers are found in all seven major basins, except for the Coastal Aquifer. They form one almost uninterrupted formation layer throughout the country. The shallow Neogene and Pleistocene aquifers are discontinuous but occupy a relatively large area of the country (Fig. 3).

**B) Flow connections** can also be discriminated into flow between basins and flows between aquifer stockworks. Between basins: All allegedly unconnected basins were found connected (many with large flow) through continuous formation (a), strongly throwing faults (b) and/or inter-basin leakage (c) as follows (Table 1):

**Table 1: Summary Aquifer connections of allegedly unconnected basins**

Basin	connected through			Basin	connected through	
	ftn. (a) & faults (b)	ftn. (b)	leakage (c)		ftn. (a) & faults (b)	ftn. (b)
NAB	WAB, EMB		CAB	WGB	EMB, WAB	LTB, WGB
MCB	WAB, CAB	WGB		LTB	EMB	WGB

Connection mechanisms: (a) continuous formation; (b) strong juxtaposing faults; (c) inter-basin leakage

Between major aquifer layers: Lateral contacts, faulting and leakage facilitate Inter-aquifer flow. The **Pleistocene** of the CAB is connected to the leaky Eocene (NAB near Gaza) and laterally to the Carmel coast aquifer (MCB). CAB in some places directly overlies the WAB, recharging it. Hence, leakage (NAB) and lateral contact (MCB) are the main mechanisms of connections. The Pleistocene of the Jordan Valley receives considerable amounts of recharge through the main graben fault, lateral contact and indirect recharge from the Eastern Mountain Aquifer (10-20mcm/yr). Deep faults juxtapose the **Eocene** against Judea Group in NAB, WGB and LTB, enabling direct exchange of flows. The **Mountain Aquifers** of the Upper Albian, Cenomanian and Turonian are the most important groundwater resource of the country, mostly with direct rain recharge. In some areas, such as the Negev, also recharge from (and discharge to) other formations takes place, usually through connections across deep throwing faults (Negev, Taninim springs, JRV main fault and Galilee). Vertical leakage occurs between sub-aquifers (GTZ, 1999), at the bottom (Messerschmid, 2003) and sometimes at the top of the Mountain aquifer system. The **deep aquifers**, only in S-Lebanon and Syria (Golan) are recharged from rain, otherwise indirectly (leakage, faults).

## 6. CONCLUSION

Israel acknowledges riparian relations and shared allocations only in those basins where it sits downstream and thus displays an arbitrary and unlawful approach with respect to transboundary aquifers and groundwater, designed only to maximize its own benefits at the great expense of its co-riparians. This study approaches transboundary and shared groundwater resources in a thorough and less arbitrary

manner. Scientific findings on the ground alone - not unilateral hydrostrategic advances - should determine the question which basins are shared and to what extent.

The established and all too often politically driven conventional wisdom seems to suggest a prevalence of discrete, mutually disconnected basins and the findings of this paper may come to the great surprise of many readers, but undeservedly so: Given the size and the regional geology of the country, this approach should rather be self-evident and employed unanimously. Much of the already existing research on a local scale has pointed to these local flow connections, however without breaking through the wall of a powerful, yet mistaken paradigm of unconnected aquifers and mini-basins. It is time to make the step and unify and align these findings in a bold new approach: All basins in Historical Palestine are shared. They constitute one common Aquifer system. Why should deep groundwater flows care about newly established and not even politically consolidated borders?

The simple consequence of this finding is: Palestinians and Israeli must share, utilize manage and protect ALL groundwater basins jointly and for the benefit of both sides. In final status negotiations over water, each basin should be investigated individually and case by case. All flow connections – both, in their natural state and under anthropogenic influence – should be weighed and quantified in order to define the best and sustainable fit for equitable and reasonable utilization. Upstream and downstream riparian relations should be taken into consideration in each case, as well as other factors, such as developing water demands, alternative and/or additional accessible water, economic abilities, needs and dependency, vital human needs and of course international law.

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