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# Paper 3 Evaluation of Water Harvesting and Managed Aquifer Recharge Potential in Upper Fara' basin in Palestine: comparing MYWAS and Water Productivity approaches

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## Abstract

Water Harvesting (WH) and Managed Aquifer Recharge (MAR) in the Upper Al-Fara' basin is essential for sustainable water resources management in the basin. Three options of WH/MAR have been identified; land reclamation, small wadi retention structures and full wadi retention dams. A pilot retention dam has been finalized in 2014 in the basin and land reclamation is practiced intensively at the West Bank. This study focuses on the comparison between two methods to determine best practices for WH/MAR. The first method uses the change in water productivity as the only criterion for the evaluation and can be considered a one parameter Cost Benefit Analysis (CBA). Water productivity is a relative simple criterion and has proven its value in water allocation management studies. The other method concerns the application of the Multi Year Water Allocation System (MYWAS), which is a more complex tool to evaluate different economic scenarios based on water demand curves. Pros and cons of both methods are analysed and results are compared. It is concluded that the highest cost effectiveness of WH/MAR measures in upper Wadi Fara' basin is reached when water is stored as soil water, while groundwater storage is in principle a no regret but less cost effective measure. Groundwater storage will always use higher water availability and is therefore a no regret measure. Both models are useful tools in decisive stakeholder participation processes to decide on optimal WH/MAR measures at basin level. MYWAS adaptations to evaluate sub-basin WH/MAR measures have been successfully incorporated. An analysis on WH/MAR measures for the total West Bank using both methodologies is recommended.

# Introduction

The Upper Wadi Fara’ basin, located at the West Bank, Palestine, has an average annual rainfall of 500 mm. Rain occurs only during winter time. Agricultural production takes place mostly in the dry spring and summer season using stored soil water and complimentary irrigation from groundwater. This research focuses on the Upper Al-Fara’ basin, a sub-catchment of the Al-Fara’ catchment (Figure 1).  This area is part of the ‘food basket’ and the main economic activity is agriculture, which also translates in the land use; approximately 71% of the land is covered with open field agriculture, greenhouses and olives. Water shortages negatively affect the agricultural yield, and a decreased yield causes decreased economic value of the agriculture (Scheierling *et al.*, 2014). Since the area greatly depends on the agricultural benefits, prevention of water shortage is of importance.

**Figure 1 -** Location upper Al-Fara' catchment

Rainwater Harvesting (RWH) and Managed Aquifer Recharge (MAR) are two options to decrease the water shortages. RWH is a method implemented to decrease rainfall generated runoff and retain precipitation water for domestic or agricultural purposes (Gould, 1999). RWH knows many different techniques and applications and can be implemented on small and large scale. Depending on the purpose and possibilities of the area RWH interventions can be divided in roof catchment systems, rock- or ground catchment systems and check- or earth dams (Gould, 1999). Another technique is the improvement of land from uncultivated to cultivated land, mainly done by de-rocking of land. This method does not use construction to store the rainwater, but directly uses the water for agricultural purposes. RWH has been widely implemented in semi-arid and Mediterranean areas to decrease water losses and increase water productivity (Biazin, Sterk, Temesgen, Abdulkedir, and Stroosnijder, 2012; Gould, 1999; Helmreich and Horn, 2009; LRC, 2010; MOPIC, 1998; Mwenge Kahinda, Taigbenu, Sejamoholo, Lillie, and Boroto, 2009; S. Shadeed, 2011; S. Shadeed and Lange, 2010; M. Sturm, Zimmermann, Schütz, Urban, and Hartung, 2009).

MAR is used to increase water availability by increasing infiltration to the aquifer and use the aquifer for storage. The use of groundwater as a storage is very valuable since the water stored is not subject to evaporation and due to filtration capacity of the soil contaminations are limited as well. There are several techniques for managed aquifer recharge, retention dams, flooding field or infiltration wells, the first two techniques require a geography suitable for infiltration (Dillon et al., 2009; EPA, 1999; Maliva and Missimer, 2012). MAR has increasingly been implemented in areas where groundwater depletion and water scarcity are issues at stake (Dillon, Pavelic, Page, Beringen, and Ward, 2009; EPA, 1999; Hughes, Mansour, and Robins, 2008; Maliva and Missimer, 2012; Rahman et al., 2013). RWH interventions can be combined with MAR interventions since the water can be used for infiltration to the groundwater and/or direct use for other purposes such as irrigation.

## Models to evaluate RWH/MAR interventions: MYWAS/WEAP and Water Productivity

To evaluate RWH/MAR interventions in the area, the technical feasibility is important to assess which interventions can be implemented and what impact they have on the water balance. However, interventions to retain and store water should not only be assessed on their technical feasibility. The construction of interventions need investments, and investors need to see if the interventions are also economically feasible before the plans are executed. When assessing the economic benefits of interventions in a certain location this can be compared to benefits created in other locations. Also, it can be evaluated which intervention in one catchment, will produce the highest returns. Even though technical feasibility might be no issue, economically there can be an optimal choice. Two methods to evaluate the economic feasibility are applied in this case study, MYWAS/WEAP and water productivity. The two methods that are essentially very different, MYWAS/WEAP is a rather complex economic tool and computes the shadow values for water and can be considered a tool to evaluate societal economic values. Water productivity is a more practical tool to measure the benefits of investments or production means, for example extensively used by the World Bank to produce country statistics[1]. It is therefore more straight forward and transparent than MYWAS/WEAP and computes the agricultural value per cubic meter of water.

“MYWAS is a tool that the user can employ to explore the consequences of various decisions and alternate circumstances” (Fisher et al., 2005). MYWAS estimates the value of water in different locations, taking into account the special values associated with water. It also estimates the benefits to be obtained from optimal use of water resources (Fisher et al., 2005). Water is regarded as an economic good, implying that it has costs and benefits. Only the most beneficial activities will be realized, finding the economical optimum (Jayyousi, 2001).

To calculate the economical optimum allocation of water MYWAS develops demand curves, these are unique per demand point. A demand curve represents the relationship between water price and the quantity of water an entity is willing and able to buy. The demand curves developed by MYWAS are constant price elasticity demand curves. It implies that the price elasticity is constant over the different price ranges of the demand curve, it is always a fraction of the demand. The inputs needed to develop a demand curve are price and quantity points. The quantity point indicates the water demand at a certain price, which is the price point. An important note for water demand is that this is not the actual water use, but the amount that a person would use when water use is not limited (Fisher et al., 2005).

Shadow values are the output of MYWAS and given per demand point. The shadow value is the sum of the marginal costs and the scarcity rent. Marginal costs are the costs of producing the water, also referred to as conveyance and extraction costs. The scarcity rent is the value of the water itself. A new project is economically feasible if the shadow values of the water are higher than the marginal costs of the water produced by this project. An important note is that the shadow values are not necessarily equal to the charged price.

Agricultural water productivity is applied to assess the productivity of the water used for agricultural purposes. It assesses whether water can be allocated differently to create a more efficient and productive use (Scheierling et al., 2014; Zoebl, 2006). Water productivity in its general form is defined as the ‘output per unit of water use’ (Molden, 1997), the output being

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[1] See http://data.worldbank.org/indicator/ER.GDP.FWTL.M3.KD. Palestine (found as West Bank and Gaza in the table had an overall water productivity in 2014 of \$ 25 per $m^3$ total withdrawn water, comparable with Jordan (\$ 31 per $m^3$). Both countries are well ranked in the top of the middle class water productivity countries.

agricultural profits. Because of its simplicity, the method is transparent, but the simplistic approach can also eliminate the more complex reality.

For the hydro-economic evaluation done in this research the economic water productivity is relevant. Data such as yield values, production costs and water costs are used to determine the net benefits of yields (Zoebl, 2006). Costs of irrigation water will be taken into account, where precipitation water is free. For the water a combination of precipitation and irrigation water is used since agricultural production depends on both water resources.

In this research the Surface Energy Balance Algorithm for Land (SEBAL) is used to determine water productivity. SEBAL solves the surface energy balance and calculates the evapotranspiration and biomass production; biomass water productivity (Zwart et al., 2008). It is an image-processing model that calculates actual and potential evaporation rates (WaterWatch). “SEBAL computes a complete radiation and energy balance along with the resistances for momentum, heat and water vapour transport for every individual pixel. The resistances are a function of state conditions such as soil water potential (and thus soil moisture), wind speed and air temperature and change from day-to-day” (WaterWatch). The method is developed by WaterWatch and validated by several European and US universities (Zwart and Bastiaanssen, 2008b) by applying and comparing the results in the field.

Current sub-optimal management of water and land leads to significant losses of water in the form of unproductive evapotranspiration and runoff in the system. Water shortage is not only caused by the annual water quantity, but also by the uneven distribution in time and space. Because the majority of agricultural activity of the West Bank is located in the Al-Fara´ watershed, it is of importance to develop methods to prevent agricultural water shortages. In order to gain more insight in the hydro-economic feasibility of RWH/MAR interventions, both MYWAS and water productivity are applied.

## Methodology

The methodology of the research is based on four main steps. First, a preliminary baseline analysis of the area is done and the water balance is computed. As a second step, the areal investigation and characteristics are used to draft RWH and MAR interventions feasible in the area. These are analysed and the costs and benefits per option are defined.

The third step is the hydro-economic evaluation using MYWAS and water productivity, of which the results lead to policy advice. The fourth step compares the outcome of the two methods and by focusing on the ranking of the scenarios the differences in approach are analysed. To decide on the most appropriate model for the case study the characteristics of the area are combined with the model approach, resulting in a recommendation for model choice. The possibilities and weaknesses of the methods, in relation with RWH and MAR, are assessed, concluding with lessons learned for future use and upscaling possibilities.

## Results

The baseline analysis resulted in the water balance:

$dS = P+Ir-ET-D-Qr$, where

dS is the change in soil storage, P is the precipitation, Ir the irrigation quantity, ET the actual evapotranspiration, D the deep percolation and Qr the runoff. Assuming the change in soil storage (dS) is zero over a year, the evapotranspiration is the only unknown and can be computed by solving the water balance. Table 1 shows that the total yearly evapotranspiration is 21.52 MCM.

Table 1 - The water balance (average over a year)

| $dS = P+G-ET - D - Q_r$ | | | | |
|---|---|---|---|---|
| | | MCM in | MCM out | mm/year |
| **dS** | Soil storage | 0,00 | | 0 |
| **P** | Precipitation | 28,00 | | 500 |
| **G** | Groundwater used for Irrigation | 5,15 | | 92 |
| **D** | Deep percolation | | 9,73 | 174 |
| **Qr** | Runoff | | 0,03 | 1 |
| **ET** | Actual evapotranspiration | | 23,39 | 436 |
| | Total | 33,15 | 33,15 | |

Concerning RWH and MAR, several studies have been done in the upper al-Fara’, resulting in three RWH/MAR options that are most suitable for the area: Land improvement, the construction of a retention dam downstream and the construction of smaller retention dams in the course of the wadi.

The land improvement will change the land use from nature to agricultural land. The productive evapotranspiration will increase and the unproductive evapotranspiration will decrease. The influence on the runoff is negligible (Shadeed, 2011). Approximately 30% (5,9 km$^2$) of the unproductive land of the upper Al-Fara’ catchment has been indicated as suitable for land improvement (LRC, 2010). The costs for improving the land are approximately 1 USD/m$^2$ (3,9 ILS/m$^2$ ) (PHG, 2015c), a total of USD 5.935.222,00 for 5,9 km$^2$. These costs do not include the investments of the first cultivation, such as seeds or seedlings greenhouses or enrichment of the ground. These extra costs are dependent on the choice of cultivation and are assumed to be equal to one year of costs of a certain land use. The maintenance costs of land improvement are assumed to be included in the standard farmers activities.

In 2013 a retention dam was built in the upper Al- Fara´ watershed. The dam was built to retain the runoff, favouring infiltration to recharge the groundwater (EQA et al., 2004; Gonzales et al., 2012; Moshe, 2008). The dam mainly influences runoff in the winter water balance. The dam has a capacity of 34.000 m$^3$, and collects the runoff generated in the upper Al-Fara’. It is assumed that the dam has enough capacity to retain all generated runoff. The retained water is estimated to be 0,03 MCM, which is infiltrating to the groundwater. The costs are USD 373.767,98 (ILS 1.440.500,00) for the construction of the dam (Nonner, 2015b). The maintenance costs of the retention dam are estimated to be USD 2.594,71 (Nonner, 2015a).

Check dams are smaller dams that are constructed in the wadi to prevent large runoff quantities to occur, the water trapped at the dams is infiltrated in the aquifer or is used as irrigation for the local farmers. Check dams are effective in small channels with a contributing drainage area of 2-10 acres (EPA, 2014; Knoop et al., 2012; VDCR, 1995). With a drainage area of 25.000 m$^2$ (6 acres) a total of 22 dams can be constructed in the wadi, resulting in

1.680 $m^3$ of water per year. The costs of a single stone check dam is approximately 645 NIS (Knoop et al., 2012; USEPA, 1992), making a total of NIS 14.448,00. The maintenance costs are estimated to be USD 259,47.

The investment costs for both the retention and the check dams are merely the costs of developing the structures. It does not take into account the investments made to distribute water or change/implement crops.

The shadow value of the upper Al-Fara' is calculated to be 1,2 USD/$m^3$ (4,2 NIS/$m^3$) for the current situation. The marginal costs for land improvement, retention dam and check dams are respectively 0,35 USD/$m^3$, 1,32 USD/$m^3$, and 0,37 USD/$m^3$. All the marginal costs are lower than the shadow value and therefore scenarios 1-3 are economically feasible.

In order to analyse the economic impact of the different RWH and MAR interventions, scenarios are developed. To assess the interventions properly the first three scenarios will consist of one of the three interventions. The other scenarios are development by combinations, developed by assessing compatibility of the interventions and the available water quantity. The retention dam is included in all the scenarios where multiple interventions are taken into account, because the dam is already in place.

*MYWAS model*

The MYWAS model is restricted to demand points that are linked to the north-eastern groundwater aquifer; Tubas, Jenin and the upper Al-Fara'.

The shadow value of Al-Fara' is 1,2 USD/$m^3$ (4,2 NIS/$m^3$), this is an effect of the high willingness to pay combined with the significant difference between demand and supply requirement (1.3MCM). When changing the available water for the Al-Fara' by introducing a retention dam, it is shown that the quantity of water is too low to change the shadow value.

The shadow values calculated by the MYWAS model are compared to the shadow values of the interventions. It can be seen that the marginal costs of the land improvement are lower than the shadow values. This indicates that the social value of water is higher than the costs of water created by land improvement, and economically the investment would be feasible. The same holds for check dams. However, it does not hold for the retention dam. A quick overview of the marginal costs of additional water from the interventions and the shadow value is shown in Figure 1.

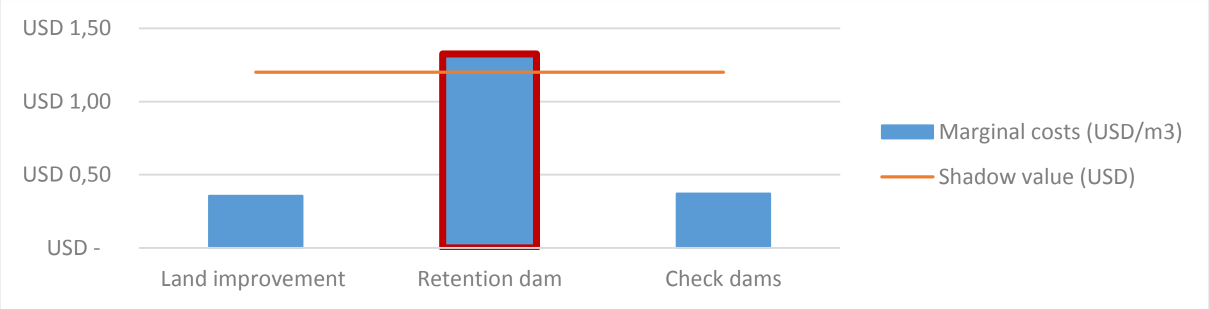

**Figure 1** - Shadow value (USD) compared to marginal costs of interventions (USD/$m^3$) (Tiehatten, 2015).

*Water productivity calculations*

Water productivity calculations present the overall Crop Water Productivity (CWP) and the CWP per land use for the current situation. For the calculations of scenario 0 the overall Crop Water Productivity (CWP) is presented (see Figure 3), also the CWP per land use (see Figure 2). Both calculations are done with the use of SEBAL.

The difference between scattered olives (rain fed) and rain fed agriculture is limited, see Figure 2. Therefore, when implementing rain fed agriculture the preference of the farmer can be decisive. For greenhouses estimated crop water requirements are used (based on a field survey done in Jenin and Sanur by the Ministry of Agriculture in 2015 and 2010), because SEBAL cannot be used in areas which are covered. The values are high compared to the irrigated open field crops, this can explained by the amount of harvest per year. Greenhouse tomatoes are harvested throughout the year, and cucumbers are harvested twice a year. The values are yearly, and if CWP is compared to the other land uses it can be seen that it is not unrealistic high.

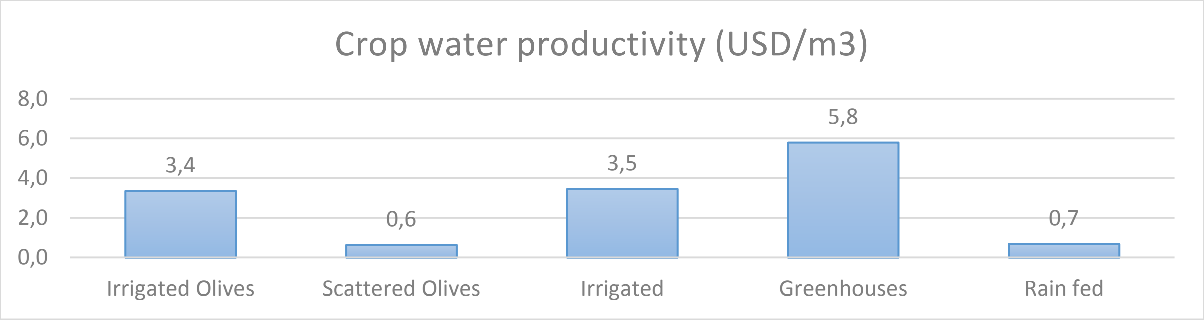

Figure 2 - Crop water productivity (USD/m$^3$) (Tiehatten, 2015).

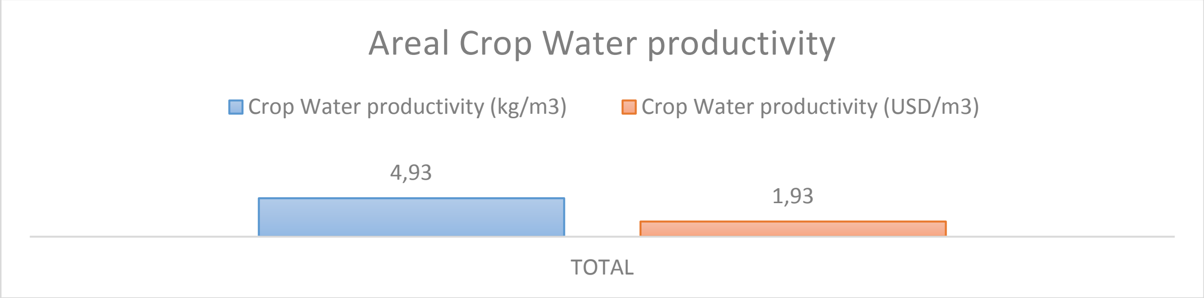

Figure 3 - Crop Water Productivity - scenario 0 (Tiehatten, 2015).

*Scenarios 1-6*

The returns per scenario (Table 3), economic CWP (Figure 4) and the payback period (Figure 5) illustrate the results from the six scenarios.

Table 2 – Returns per year per scenario

| | **Land Improvement** | **Retention Dam** | **Check Dams** | **LI & RD** | **CD & RD** | **All** |
|---|---|---|---|---|---|---|
| *Returns (USD)* | 1.141.389,00 | 29.001,00 | 1.595,00 | 1.170.390,00 | 30.596,00 | 1.171.985,00 |

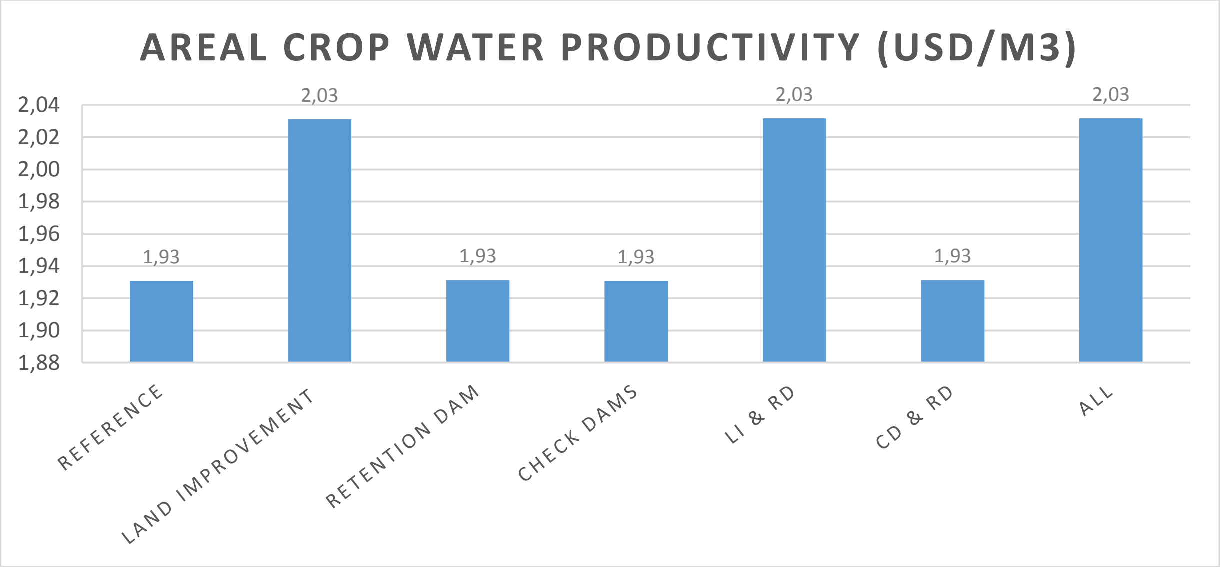

Figure 4 - Crop Water Productivity (USD/m$^3$) per scenario (Tiehatten, 2015).

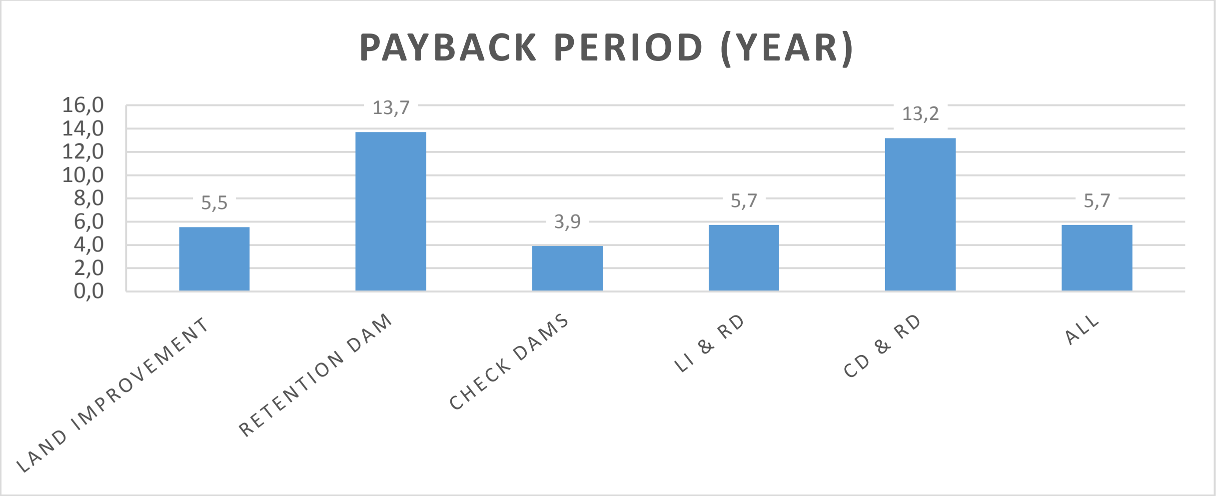

Figure 5 - Payback period per scenario (Tiehatten, 2015).

The results show that the areal economic CWP (USD/m$^3$) is only influenced by the introduction of land improvement. When implementing a dam, the water that can be used for irrigation increases and causes a change in the acreage per land use. The additional water makes more land available for more productive land use from rain fed agriculture, 0,7 USD/m$^3$, to irrigated agriculture, 3,5 USD/m$^3$. This increases the areal CWP, however, the acreage change only increases the areal CWP with 0,0006 USD/m$^3$, and therefore it does not show in Figure 4. For the land improvement the rainwater that was unproductively used by nature is now productively used by cultivated land, this is a larger change and therefore it can be observed in Figure 4. Furthermore it causes an increase in net benefits because nature does not create yield benefits, increasing the CWP.

To calculate the payback period for the scenarios, the total investments are compared to the returns per year. The returns of the check dams are low but because of the low investments the payback period of the check dams is lowest of all interventions, 2,6 years. The payback period of the retention dam is significantly higher because of the low investment-return ratio. Land improvement returns are high, making the payback period relatively low.

In Table 4, the 6 scenarios are ranked from 1-6, 1 for the most beneficial and 6 for the lowest. For equal scenarios the same ranking is given. The lowest sum of the ranks is regarded as the optimal solution, this shows that combining the three interventions is the optimal scenario. Combining the three interventions give a high areal Crop Water Productivity, relatively low payback period and highest returns. Where the check dams have no effect on the areal Crop Water Productivity and almost no returns, but they are relatively cheap and could be regarded as a 'no regret' intervention.

Table 3 - Crop Water Productivity - ranking scenarios

| ***Ranking*** | **Land Improvement** | **Retention Dam** | **Check Dams** | **LI & RD** | **CD & RD** | **All** |
|---|---|---|---|---|---|---|
| *Economic WP* | 1 | 2 | 2 | 1 | 2 | 1 |
| *Payback* | 2 | 5 | 1 | 3 | 4 | 3 |
| *Returns* | 3 | 5 | 6 | 2 | 4 | 1 |
| *Overall* | 6 | 12 | 9 | 6 | 10 | 5 |

## Discussion

*Sensitivity of input data*

To make an evaluation of the sensitivity of input data, a sensitivity matrix for both MYWAS/WEAP and water productivity is computed (Tiehatten, 2015). For MYWAS/WEAP the Irrigation Crop Water Requirement (ICWR) and the willingness to pay show the highest uncertainty and therefore most effect on the results. The shadow values, as computed by MYWAS/WEAP, are an underestimation regarding the willingness to pay, but an overestimation regarding ICWR. Because ICWR has more effect on the outcome the shadow values, the results are regarded as overestimations (Tiehatten, 2015).[2]

For water productivity the data with the highest uncertainty and the biggest effect on the results are the economic benefits per crop and the yield (kg). The results from water productivity are regarded as an overestimation because of the overestimation of the benefits of the computed yield. (Tiehatten, 2015).

*Limitations and opportunities*

The result of MYWAS is one value, which can be of good use when communicating to policy makers who are familiar with economic models and the meaning of shadow values. However discussing the result with people in the field is difficult, because their lack of economic knowledge. Also, to develop a demand curve, MYWAS/WEAP uses only one parameter to express the complex system of water requirements in an agricultural area and implementing variations in the agricultural system is not possible (Vaughan, 2011).

For the complexity of agricultural practices, predictions are difficult to make. The model can include a growth factor, but this is a complicated parameter to estimate (Fisher *et al.*, 2005a). One of the complication results from sub-optimal irrigation choice of farmers. MYWAS/WEAP cannot be used to support specific agricultural policies, such as determining

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[2] With a price point of 4 NIS (decrease of 20%) and ICWR of 410mm (decrease of 20%) the shadow value is reduced to 3,4 NIS.

the most productive crop, it is a model indicating the economic values of water (Fakhri *et al.*, 2014).

Water productivity is used to create an overview of the efficiency water. The method is transparent and the results are applicable to the field situation. Therefore, discussing and debating the results with non-experts or in the field is an option and can be beneficial for both the results as for the communication to the involved parties. A limitation of using CWP is that it is not possible to advice on a more beneficial crop, since not all crops have the same value per kg. The non-water costs of production can be determined per crop and are not very sensitive to differences in farm techniques. However, when determining the benefits per crop, fluctuation in the market price is not taken into account, this is a limitation to the accuracy of the economic CWP.

Interventions adjusting the status quo of the groundwater table also affect other catchments, but these effects are not part of this research. Also, the research is limited to the agricultural demand and use of water and merely evaluates the impact of interventions in the area. It does not advise on changes in agricultural techniques, crop choice or crop calendars.

## Conclusions

Three interventions are technically feasible in the upper Al-Fara': land improvement, a retention dam and check dams. In total six scenarios are developed combining these interventions to analyse the economic feasibility of the interventions. The retention dam is already implemented and therefore always included in assessing multiple interventions scenarios.

The results of MYWAS/WEAP show that the shadow value of the water in the upper Al-Fara' is lower than the marginal costs of the additional water of the retention dam, indicating that the retention dam is not the optimal intervention. Check dams and land improvement are evaluated as economically feasible.

The results of water productivity show three main criteria to evaluate the scenarios: economic water productivity, returns and payback period. Land improvement is the only intervention significantly increasing the water productivity in the area, also the returns are highest. Even though the investments of land improvement are high, the investment return ratio results in an average payback period of 5,5 years, compared to 13,7 years for the retention dam, and 3,9 years for the check dams.

A policy advice can best be given using the results from both methods. MYWAS/WEAP results show that the retention dam is not the optimal solution in the area. This is explained by the low runoff rate and therefore the low additional recharge. Water productivity results do not indicate a negative economic value for the retention dam, however it does not increase water productivity and has a low investment-return ratio (payback period is more than twice as long as for land improvement). The optimal economic choice would be to combine the land improvement with the check dams.

The use of both methods provides supplementary insight and data. Therefore, an advice based on supplementary use of the results of both methods is broader supported; it is based on both water economics (MYWAS/WEAP) as agricultural analysis (Economic CWP).

SEBAL can be used to prepare input data for both methods, not only for water productivity. Especially to compute the Irrigation Crop Water Requirement (ICWR) data in MYWAS/WEAP, now based plant specific general data. ICWR has a high effect on the results and has a high uncertainty. By using SEBAL, this data can be determined using actual field data, making it more accurate.

Upscaling can be done for both methods, provided that the input data is available on a detailed level appropriate for that scale. SEBAL is a useful tool for both methods: for water productivity evapotranspiration and biomass production can be determined and for MYWAS/WEAP the ICWR on larger scale can be determined. However, the availability of good land use map of sufficient detail is a starting point. Without this, limited conclusions can be derived from SEBAL images. Also special attention is required for the input data with the highest impact on the results and the highest uncertainty: ICWR and willingness to pay for MYWAS/WEAP, benefits per crop and yields for water productivity.

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