Incentives to reduce groundwater consumption in Yemen[1]

P.J.G.J. Hellegers[a], C.J. Perry[b] and Nasser Al-Aulaqi[c]

[a]LEI-Wageningen UR, P.O. Box 29703, 2502 LS The Hague, The Netherlands,
e-mail: petra.hellegers@wur.nl, phone: +31 317 484788, fax: +31 317 484490
[b]Consultant, UK
[c] Water and Environment Centre (WEC) of Sana'a University in Yemen

Abstract In this paper options for changing the incentive structure to reduce unsustainable groundwater consumption in Yemen are evaluated. Special attention is paid to incentives that decrease the profitability of irrigation water use and subsidies on improved irrigation technology. Although the literature and economic theory suggest that the range of possible incentives is wide (water pricing, metering, water rights, water markets, taxes, subsidies, information, participatory management etc.), the results of this study show that the range of potentially effective incentives in the Yemeni political context is more limited due to difficulties of implementing and enforcing change. The Yemeni case is unique, as there is a close linkage between water and qat production. Reducing water consumption will substantially reduce the benefits from qat production and consequently farm income, which is a politically sensitive way of bringing about a balance between supply and demand of water.

1. Introduction

Until the 1970s, water use in Yemen was sustainable. Agriculture utilized water resources that are rainfall-dependant and thus, while the country was exceptionally water-short, an approximate annual balance between renewable supply and utilization was maintained. This changed dramatically with the arrival of tubewell technology that allowed exploitation of water from deep aquifers. Exploitation of this resource was no longer "naturally" constrained by annual rainfall, and by now use in many areas is unsustainable.

The current economic incentive structure seems to encourage instead of discourage groundwater extraction. Diesel is currently highly subsidized, which lowers the costs of power and consequently the cost of water – making irrigation more profitable. A substantial share of the national budget (25%) is spent on diesel subsidies and 8% of GDP. Investment in improved irrigation equipment is also subsidized – which again makes irrigation more profitable while potentially saving power. Moreover, the qat market is protected by obstacles to qat imports (so that domestic prices of this crop are higher than would be the case under free trade).

The objective of this study is to review incentives-primarily economic incentives-that can limit the demand for irrigation water and to assess their usefulness in the context of the following three -rather different- basins (see Figure 1). In the Sana'a basin, where the overdraft is substantial (around four to five times recharge), the remaining aquifer life is thought to be around 15 years. In Taiz basin, where overdraft is less severe (abstractions are estimated to be double recharge), the water table is falling and aquifer life unclear. In wadi Hadramaut, where overdraft is most severe (around seven times recharge), the aquifer is extremely large.

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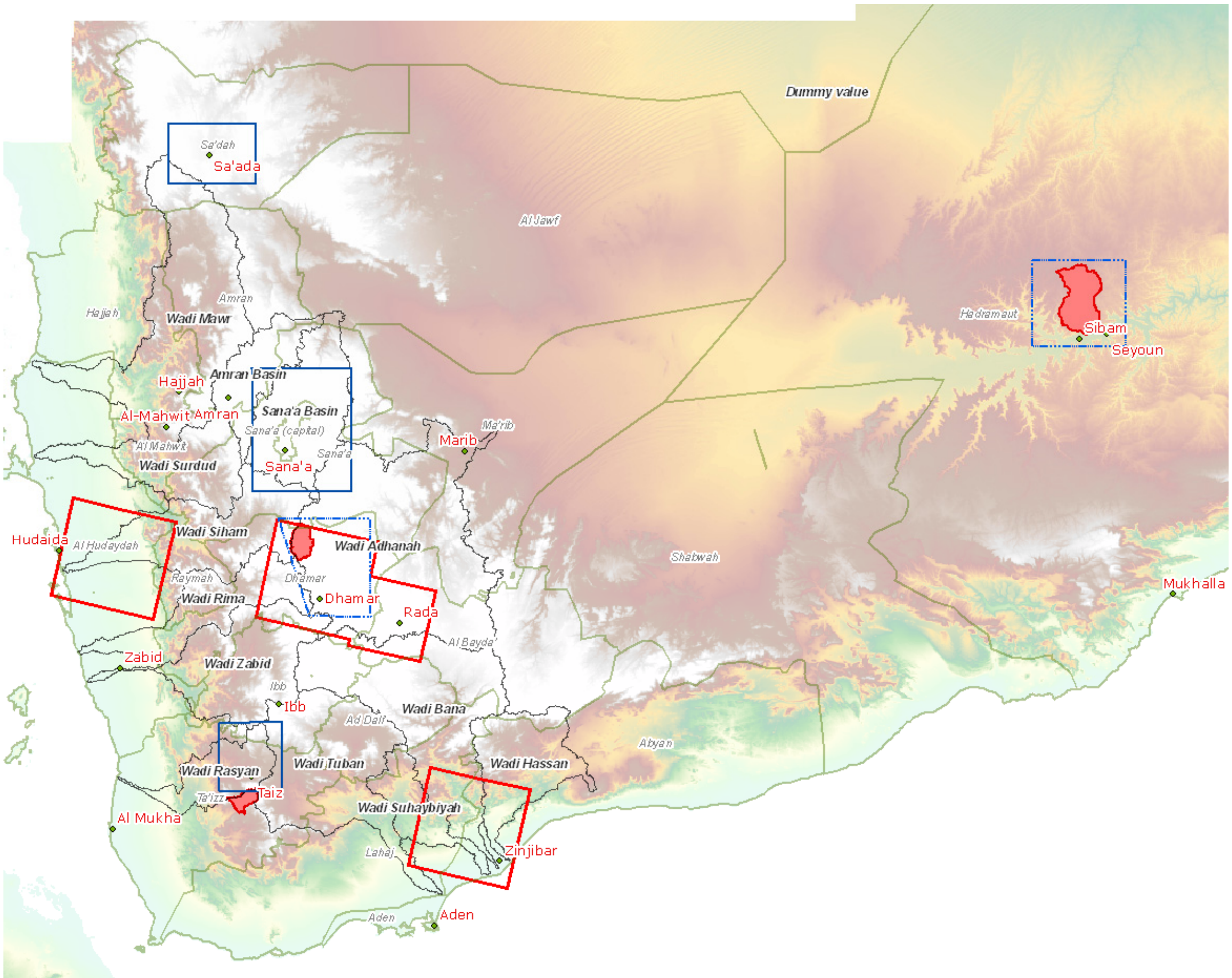

Figure 1. Location of the three case study areas: Sana'a Basin, Taiz Basin (Wadi Rasyan) and Wadi Hadramout (Seyoun).

A review of the literature on the theoretical role of economic instruments in limiting the demand for irrigation water by Bosworth et al. (2002) showed that the range of possible incentives is wide (water pricing, metering, water rights, water markets, taxes, subsidies, information, etc.).

The impact of incentives that decrease the profitability of irrigation water use -by increasing the costs of water or by decreasing the price of outputs- on water saving is studied in section 2. Whether changes in the policies that affect input and output prices will provide incentives to reduce groundwater use will be studied on the basis of the crop budgets of the main irrigated crops. The cost of pumping and delivering groundwater will be compared to the value of irrigation water use on the basis of the crop budgets of the main irrigated crops. When the costs are substantially below the value, it is unlikely that policies that double or triple the costs of water will substantially reduce groundwater use. A more significant increase in the costs of water is required. This will substantially reduce farm incomes, which may be politically unacceptable.

Costs of pumping can be calculated on the basis of the depth of pumping. The Residual Method is used in this study to derive the value of water, see Young (2005) for an extensive review of the theoretical foundations, uses, benefits and limitations of this method. The basic approach relies on the fact that the value to a producer from producing a good is exactly exhausted by the summation of the values of the inputs required to produce it. If the value of one input is unknown (which in this study is the value farmers place on water), then the value of that input can be found by making the unknown value a function of the price by quantity of the output, less the values of all known inputs, divided by the quantity of the unknown input. Young (2005) describes it as the 'value of water' or 'net return to water' or 'residual value'.

The impact of subsidies on improved irrigation technology, which is currently the cornerstone of donor policy, on water saving is studied in section 3. It consists of hardware (replacing open earthen conveyance channels with pipes, and replacing traditional technology with on-farm drip) and software (recommending improved schedules, appropriate quantities, and crops that are more productive per unit of water consumed). Some donor projects even subsidize 70% of the capital costs of investments in drip. These projects assume/claim to save large quantities of water and greatly increase the productivity of water. Whether this is really the case is questioned in this paper. Attention is also paid to the extent to which projects actually extend the life of the aquifer.

A broader review of the various options to limit groundwater extraction is presented in section 4. Finally, conclusions are drawn and recommendations are formulated in section 5.

2. Incentives that decrease the profitability of irrigation

In this section the impact of policies that affect input and output prices on water saving is studied. The cost of pumping groundwater are compared to the value of irrigation water use on the basis of the crop budgets of the main irrigated crops.

The unit costs of pumping groundwater ($\$/m^3$) in the Sana'a basin increase according to the literature (World Bank, 2006) as follows with the depth of pumping: at a depth of 100 m, 200 m and 400 m costs are respectively 0.15 $\$/m^3$; 0.21 $\$/m^3$ and 0.28 $\$/m^3$. To be able to derive the costs of pumping at various depth of pumping in the three case study areas, the unit cost of groundwater pumping y^a (in $\$/m^3$) are estimated as a function of the depth of pumping x (in m). Figure 2 shows that the unit costs of pumping are increasing with the depth of pumping, but at a decreasing rate. The following relationship has been estimated:

$$y^a = 0.0194\, x^{0.448}. \qquad (1)$$

The depth of pumping varies largely within basins. Results from field surveys done in this study, show the following average depths of pumping: 180 m in Sana'a basin, 94 m in Taiz and 63 m in wadi Hadramaut. Unit cost of pumping are respectively: 0.20 $\$/m^3$; 0.15 $\$/m^3$ and 0.12 $\$/m^3$. A substantial share of it consists of diesel cost (respectively 0.11 $\$/m^3$; 0.08 $\$/m^3$ and 0.07 $\$/m^3$).

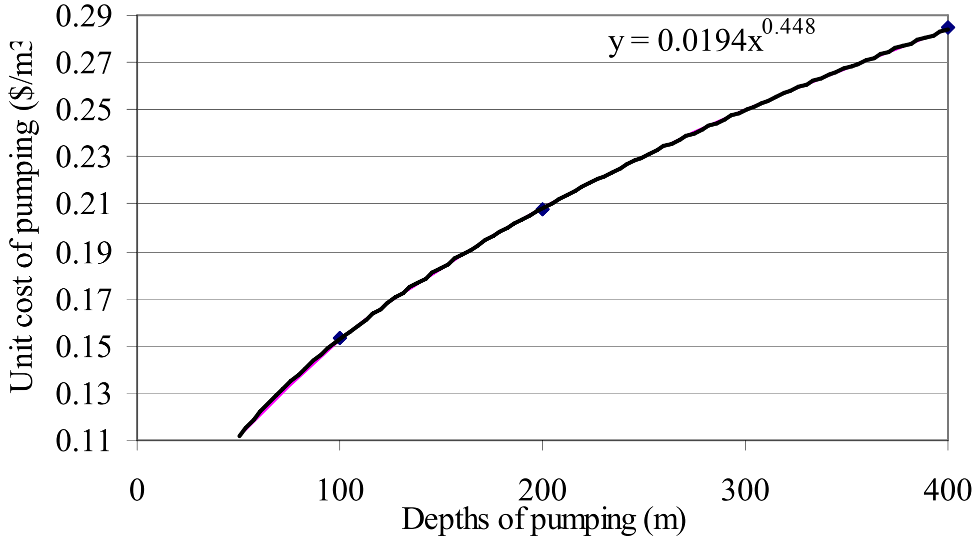

Figure 2. Unit cost of groundwater pumping as a function of the depth of pumping

By subtracting the cost of production (excluding the costs of water) from the gross production value, the value of water per unit of water applied can be derived (see Table 1, 2 and 3) . It is, however, important to note that 'net returns to water' are difficult to compute precisely for a number of reasons. Firstly, the precise technical coefficients (yield/ha, water use, etc.) will vary across farms and by year. Second, some inputs are difficult to capture accurately because they are not monetised (like family labour), or may be subject to distortions. Third, a precise analysis of the impacts of policies would also require identification of marginal returns, since these are the values that induce responses. In this study marginal returns to water are not derived (the extra income that a farmer would derive from an additional cubic meter of water), since in general under conditions of water scarcity, average value is a reasonable proxy for marginal value.

Crop budget data -based on water requirements of traditional technology- for the main irrigated crops in the Sana'a basin , Taiz basin and wadi Hadramaut are presented in Table 1, 2 and 3. Some crops have relatively low returns[2] (alfalfa in Sana'a and Hadramaut; sorghum in Taiz), that are even smaller than the cost of pumping water. These crops are either grown for home consumption or as feed for livestock, and are less sensitive to changes in the profitability. Such subsistence farming is often cross-subsidized by benefits from more profitable crops, like qat. This illustrates that farmers do not always behave in a rational manner, which means that it is not so straightforward to assess the implications of economic incentives. For the other crops, the value of water in Sana'a and Taiz is about 4-8 times higher than the cost of pumping. This means that it is unlikely that policies that double or triple the costs of pumping water will substantially reduce water use. A more significant increase in the costs of water is required. This will, however, substantially reduce farm income.

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2 Though by international standards, most of the returns achieved in Yemen are extremely high.

Table 1. Crop budgets of qat, grapes, tomatoes and potatoes in Sana'a basin

	Qat	Grapes	Alfalfa	Tomatoes	Potatoes
Gross production value ($/ha)	14,823	6,612	3,000	6,060	4,480
-crop yield (kg/ha)	900	8,700	18,750	20,200	11,200
-crop price ($/kg)	16.47	0.76	0.16	0.3	0.4
Costs of production ($/ha) excl. costs of water	680	708	375	793	531
-costs of fertilizer, pesticides, clay ($/ha)	354	381	202	427	286
-costs of labor ($/ha)	326	327	173	366	245
Net production value ($/ha) or net returns to land	14,143	5,904	2,625	5,267	3,949
Actual irrigation water applied (m^3/ha)	12,500	8,500	14,200	5,750	5,420
Net returns to water ($/$m^3$) or value of water	1.13	0.69	0.18	0.92	0.73
Costs of pumping water at a depth of 180 m ($/$m^3$)	0.20	0.20	0.20	0.20	0.20
Value/Cost Ratio	**5.6:1**	**3.5:1**	**0.9:1**	**4.6:1**	**3.7:1**

The total costs of pumping water can be calculated by multiplying the unit cost of pumping water by the quantity of irrigation water applied. It has a rather high share in total production costs. The costs of water for qat in Sana'a are 2,500 $/ha, which is about 80% of total production costs.

Table 2. Crop budgets of qat, onions, sorghum and mango in Taiz basin

	Qat	Onion	Sorghum	Mango
Gross production value ($/ha)	11,970	4,500	238	10,990
-crop yield (kg/ha)	700	15,000	720	15,700
-crop price ($/kg)	17.1	0.3	0.33	0.7
Costs of production ($/ha) excl. costs of water	680	720	30	680
-costs of fertilizer, pesticides, clay ($/ha)	354	387	13	354
-costs of labor ($/ha)	326	333	17	326
Net production value ($/ha) or net returns to land	11,290	3,780	208	10,310
Actual irrigation water applied (m^3/ha)	9,980	6,100	6,700	18,800
Net returns to water ($/$m^3$) or value of water	1.13	0.62	0.03	0.55
Costs of pumping water at a depth of 94 m ($/$m^3$)	0.15	0.15	0.15	0.15
Value/Cost Ratio	**7.5:1**	**4.1:1**	**0.2:1**	**3.6:1**

Returns to water are relatively low in Hadramaut (see Table 3). The ratio between the value of water and the unit cost of water (0.12 $/$m^3$) ranges from 2.7:1 for onions to 1:1 for alfalfa. This means that doubling the cost of water may change the cropping pattern, while tripling the cost may reduce groundwater use substantially (as there are no substitutes with high returns to water).

Table 3. Crop budgets of dates, alfalfa, wheat and onions in wadi Hadramaut

	Alfalfa	Wheat	Onions
Gross production value ($/ha)	3,188	1,800	4,500
-crop yield (kg/ha)	18,750	3,000	15,000
-crop price ($/kg)	0.17	0.6	0.3
Costs of production ($/ha) excl. costs of water	413	400	345
-costs of fertilizer, pesticides, clay ($/ha)	222	300	186
-costs of labor ($/ha)	191	100	159
Net production value ($/ha) or net returns to land	2,775	1,400	4,155
Actual irrigation water applied (m^3/ha)	22,590	7,000	13,096
Net returns to water ($/$m^3$) or value of water	0.12	0.2	0.32
Costs of pumping water at a depth of 63 m ($/$m^3$)	0.12	0.12	0.12
Value/Cost Ratio	**1:1**	**1.7:1**	**2.7:1**

The current subsidy on diesel for irrigated agriculture decreases the unit cost of pumping water. In 2007, farmers paid a price of 0.177 \$/litre of diesel (35 Y.R./liter). The impact of a higher diesel price of say 0.35 \$/litre of diesel (or 70 Y.R./litre) will raise the unit cost of pumping to respectively 0.31 $\$/m^3$; 0.23 $\$/m^3$ and 0.19$\$/m^3$. This may reduce groundwater use in Hadramaut. It is, however, not likely that it will affect crops with a high return to water, like qat and grapes. It may trigger substitution of crops with low returns to water by crops with high returns to water.

The value of water and the unit costs of pumping water for crops, like grapes, tomatoes, potatoes and mango will almost break-even under a 65% reduction in output prices. A reduction of about 80% in the output price of qat is required to significantly affect the profitability of qat. This will reduce rural incomes substantially and is therefore politically sensitive.

Since returns to water vary a lot among crops and basins, a change in the costs of water may affect the profitability of some crops and some basins more than others. Changes to national incentives (like by increasing the price of diesel) would make for instance irrigation unviable in Hadramaut before impacting significantly on demand in Sana'a or Taiz. The danger of increasing the price of water is that farmers will convert on a large-scale (to the extent that agro-climatic conditions allow) to qat production as for this crop the costs of water are substantially below the value of water. This will trigger groundwater extraction even further (as actual irrigation water use of qat is above the average). The increases in costs required to impact on the profitability of qat will make other irrigated crops non-viable. In other words incentives that decrease the profitability of irrigation at the farm level can trigger farmers to use water more productively, but are not the basis for bringing about a balance between demand and sustainable supply.

The three policy objectives of Yemen are closely interlinked: to maintain or increase agricultural incomes; to reduce over-abstraction of water; to be mindful of the implications for the poor. Given that agricultural income is essentially a function of water consumption by crops, and that the rural poor are dependent on agriculture, there are obvious tensions between these objectives. In fact, any intervention that decreases profitability of irrigation water use in order to decrease water demand in consequence decrease farm incomes. This is true whether the cost of water is increased, or the price of crops is decreased. The net result is a fall in the profitability of water use, and a parallel fall in farm incomes. Such effects could only be avoided by compensatory payments to farmers, by identifying alternative higher value crops, or by government support to the price of competing less water-consuming crops. The introduction of compensatory payments is, however, administratively complex and open to misuse as the administrative capacity of the government is not strong. The scope to increase incomes by shifts in cropping pattern (other than converting more non-qat areas into qat) is limited. Farmers already achieve exceptionally high returns to water by international standards, especially for qat. Finally, a crop subsidy programme is unlikely to be affordable given the state of the country's finances, and is difficult to target.

3. Subsidies on improved irrigation technology

In this section the implications of improved irrigation technology on water saving are addressed. It builds upon findings from the field of other studies. The water saving report (MAI, 2008) provides the basis for the analysis. It presents water saving results of demonstration farms established under the groundwater and soil conservation project. The average percentage change in key components of the crop budget resulting from replacing open earthen conveyance channels by pipes, and replacing traditional on-farm irrigation techniques by modern systems are reported in Table 4. Similar claims of water saving and increased yield are made in other reports.

Table 4. The average percentage change in water saving and crop yield of demonstration farms

	Water Applied	Fuel	Labor	Crop Yield
Pipe vs Open conveyance Channel	-18%	-23%	-22%	+17%
Modern vs Traditional technology	-35%	-36%	-34%	+21%
Combined	-47%	-51%	-47%	+41%

At the demonstration farms the productivity of water increases by a factor of 2.7[3]. This figure is a measure of increased profitability of irrigation: or put in another way, if the farmer continues to pump the same quantity of water from the aquifer with the modern technology, he could irrigate almost twice the area AND get 40% more production per unit area. For the *farmer*, the "savings" in expenditures are real and increase the profitability of pumping, which might trigger pumping. The value/cost ratios of 4-8:1 presented in the Tables 1, 2 and 3 are for traditional irrigation technology. The modern irrigation technology imply value/cost ratios in the range of 10-20:1. The "savings" farmers experience from improved irrigation technology delivers a private benefit and provide the scope to maintain pumping rates and increase his irrigated area or to sell water. So, the observed changes in the profitability of irrigation to the farmers are clear and undisputed, while doubts remain about the extent of the positive impact of modern technologies on aquifers.

For the *aquifer* the distinction between *gross* and *net* water savings is critical. What is actually happening to the "excess" deliveries applied through traditional techniques? Would it have been a recoverable loss or not? To what extent does modern irrigation technology increase the lifetime of the aquifer? Is a higher productivity of water per unit of water consumed realistic?

Comparing water delivered by the well with traditional technology to water delivered with modern technology is a measure of *gross* water saved, but only a hydro-geological assessment of where the large quantities of "saved" water were previously going can firmly conclude the extent of *net* water savings. Inevitably some water is lost to non-beneficial evaporation, especially near earthen water courses—but extensive literature on this topic (Perry, 2007) points to extreme caution in assuming that the difference between "before" and "after" deliveries is an accurate indicator of savings available for alternative use. Under the complex hydro-geological conditions of Yemen, return flows from excess irrigation deliveries or seepage from delivery channels may not reach an usable aquifer because of capillary rise from the wet soil matrix, local pollution in the upper soil layers, and local impermeable layers due to perched water tables. Each of these will happen; whether they are common or significant is unknown and should be studied at every individual site where introduction of improved irrigation technology is proposed. Certainly Yemenis have exploited relatively shallow aquifers in many places for many years. In all those locations, recharge certainly "works", and is the source of an exploited resource. Regarding non-beneficial evaporation (E)—evidence from the literature (Burt et al. 2005) suggests that if irrigation is reasonably well managed, E is rather small and difficult to reduce. If irrigation is strongly localized to the specific plant (leaving the surrounding soil bare), then E will be reduced but transpiration will increase somewhat to maintain the energy balance. Of course, if irrigation

3 Productivity = crop production/water use = (1 + 0.41)/(1 - 0.47) = 2.7

is really badly managed, then losses to E are likely to be significant. One would expect where water is scarce and expensive, and crops generally high-value, water would be well managed at the farm level. Losses in unlined conveyance systems, on the other hand, can be substantial.

The conclusion is that there are *net* water savings from improved irrigation technology, but they are likely to be smaller than the *gross* water savings assessed on the basis of measured deliveries.

In some parts of Yemen where irrigation water losses are recoverable, like in parts of Taiz and parts of Hadramaut, improved irrigation technology will save less water than calculated (as "losses" are re-used). In other parts like in parts of Sana'a Basin where irrigation water losses may be non-recoverable, improved technology might save some water, but it depends on the remaining size of the aquifer whether investment in improved technology is worthwhile. If the anticipated depletion of Sana'a's aquifers is indeed within 15 years, investments in improved technology may extend the lifetime of the aquifer by only a few years (assuming a gradual program for project implementation to cover the entire irrigated area with the new technology). JICA (2007) points out that the extension to the life of the Sana'a basin aquifer would indeed be only a few years if the technology works well and saves water to the extent claimed. It further points out that sustainable water use in the basin requires a 70% reduction in the irrigated area.

Another issue, which proved more contentious, centered on the extent to which improved irrigation technology allows higher productivity of water per unit of water consumed. In some cases farmers may practice controlled deficit irrigation when improved technology allows more precise scheduling and application of water. Most scientific papers argue that biomass formation is a linear function of transpiration, so that yield increases are the direct result of the increased transpiration resulting from a better irrigation service. Nevertheless, deliberate stressing of certain crop at specific periods in the growth cycle may result in increased water productivity (Goldhammer and Viveros, 2000). Whether Yemen—and crops such as qat and grapes and yet to be enforced quantitative restrictions—meet these conditions remains to be demonstrated.

In considering this important issue, the context is critical: farmers should be *first* persuaded to accept reduced water deliveries to the field. *Then* they should be assisted to find better ways to utilize that resource through improved irrigation scheduling, planning dates, or crop selection. However, in Yemen it is the other way round: farmers are *first* asked to invest in new technology and *then* not to extend their irrigated area to reduce water consumption, which does not work.

To summarise, it is certain that the new technologies make pumping far more affordable and profitable than traditional technologies for farmers on the basis of energy savings, which are real but have the unfortunate side-effect of making beneficial consumption cheaper. Controlling pumping, areas and cropping patterns may consequently become more difficult in the future.

The extent of 'real water savings' is, however, uncertain. There are a number of location specific situations in which water savings would be achieved—for example where aquifers are polluted, where evaporative losses are high, or where capillary rise is prevalent. A local analysis of the extent of water savings in the specific hydro-geological context is needed to justify investments in improved irrigation technology. This would be a step forward but not a solution. Certainly, unqualified claims of water savings are misleading to policymakers and often factually incorrect.

4 A review of the options

Other incentives, frequently referred to in donor reports, include the introduction of tradable water rights and/or water markets. *Water markets* are already active in Yemen. Well-owners sell water to neighbours and also to tankers that transport the water to distant users (domestic and agricultural). The impact of this trade is economically desirable to the extent that it ensures that water is reallocated from lower to higher value uses. However, where sustainable water rights are neither defined nor enforced, water markets simply strengthen the pressure of demand on already overexploited resources and are thus negative in their impact on sustainable resource use.

While frequent reference is made in the literature and reports on Yemen to the need for ‘formal" water markets and the benefits of *tradable water rights*, hardly any attention is paid to the need to define water rights, and the fact that definition of rights must precede trading. Water rights are currently loosely defined on the basis of historic use, and entitlement to exploit what lies beneath one’s land. Converting this, through the formal sector, into quantitative entitlements, enforced by the rule of law is an exceptionally difficult task, in which many countries are failing.

Importing qat has been on the agenda in Yemen for some time (NWSSIP, 2005). An earlier attempt to implement this was strongly resisted by vested interests, and failed. Now, there is discussion of establishing a farmer-owned operation in Ethiopia, where qat can be grown for export, and the revenues distributed among the Yemeni farmers who reduce their qat production. Substantial imports of cheap qat would be expected to lead to an increase in total consumption, but a decrease in domestic production and consequently water saving if no other crops are grown instead. But also lower rural incomes *unless* the profit from domestic production is so high that farmers can compete with imported qat (perhaps by charging a premium for fresher “local" produce). It may also include a positive health impact of reduced exposure of qat to pesticides.

It shows that modification of agricultural and food trade policies—can influence demand for water by making water-intensive crops less attractive. It reduces the demand for water (positive impact), but also the benefits derived by the farmers from using the resource (negative impact). It is important to note in this respect that, while instruments that change the incentive structure at the farm level can influence farmers towards using less water and using it more productively, such interventions are not the basis for bringing about a balance between supply and demand.

Although the literature and economic theory suggest that the range of possible interventions is wide (water pricing, water rights, water markets, taxes, subsidies, etc.), the range of potentially effective interventions in the Yemeni political context is far more limited as summarized below.

Regulation has limited prospects for success as a government-administered scheme. A dominant characteristic of Yemen is its political power structure, which comprises an exceptionally strong presidency, and powerful traditional institutions in rural areas who wield great influence in the day-to-day lives of most of the farming community. Between these two extremes, government agencies are weak: "central" rules limiting or regulating the actions of local people will have little impact *unless* the rural elites are persuaded of the argument and become part of the implementation process. Support to these community actions is recommended in this study. Local communities and water user associations can play a big role in managing water.

Direct incentives currently consist most importantly of a protected qat market (so that domestic prices are higher than would be the case under free trade); highly subsidized diesel; and subsidies to improved irrigation technology. As noted above, the case for and against opening the qat market is not straightforward. Socially the impact would be negative (increased consumption); medically the impact would be positive (less exposure to pesticides); economically, the impact is negative—unless a productive alternative use is identified for the "saved" water. The diesel subsidy is significant primarily as a macro-economic issue. It is a serious drain on the budget—but dealing with that problem will not substantially affect the demand for water, and will have many other impacts. The subsidies to improved irrigation technology seem to be unnecessary.

Other conventional incentives (water rights, metering, water pricing, controlling pumping, etc) have very limited prospects for success as government-administered schemes. Where sustainable water rights are neither defined nor enforced, water markets simply strengthen the pressure of demand on already overexploited resources and are thus negative in their impact on sustainable resource use. Water rights are currently loosely defined on the basis of historic use, and entitlement to exploit what lies beneath one's land. Converting this, through the formal sector, into quantitative entitlements, enforced by the rule of law is a difficult task. However, if local groups are persuaded that self-regulation is critical, some forms of regulation may evolve.

Persuasion based on information is an universal priority. At the *national level*, a "water budget", setting out which activities use how much water would be powerful in mobilizing political will to address the overdraft issue. *Locally*, information on projected aquifer life would be powerful in underpinning traditional institutions. This is particularly the case given the relative weakness of the central government (and strength of local traditional institutions). If local forces are to be mobilized to address local issues, the foundation for their actions will be awareness: how much water do they have; where is it going? Whether the advertised savings are real or not is one issue; a far more important issue is whether savings offer a route to a significantly different future. At the *farm level*, information is usually conveyed through extension services and there is a need to strengthen these (especially the Irrigation Advisory Services).

The locational differences between the study areas have implications for priorities. In Sana'a the priority is to protect water supplies for the highest value use of all—domestic consumption. This priority is accentuated by the fact that those leaving the land will migrate to towns and cities. As there is currently a lack of accurate information regarding the remaining aquifer life, a technical study is recommended to define the areas around Sana'a required to be reserved for non-agricultural use. So, a key element in the Sana'a basin will be cessation of agriculture in the vicinity of Sana'a to protect urban supplies. In a few better-endowed areas, groundwater irrigation will continue, but the scale will eventually be a fraction of today's use. In Taiz the situation is less clear—the scale of irrigation will eventually decline substantially—but there is recharge, and the sustainable level of irrigation may be significant locally. The highest priority is information: what are the sustainable (local) aquifer yields; what are the recharge mechanisms; are there areas that will be totally depleted in the foreseeable future? In Hadramaut overdraft is more severe than in Taiz, but the aquifer is very large, so the time available to reach a new equilibrium is much longer. In Hadramaut, while the level of over-abstraction is high, and a fuller understanding of local hydrogeology is needed, the remaining resource is very large.

5 Conclusions and recommendations

There are two options of bringing about a balance between water demand and sustainable supply —either collective actions at the local level must enforce reductions in use, or the balance is achieved by default as wells dry up. Forty years ago, Yemen's water consumption was in balance with its available resources. Forty years from now, and in most areas far sooner, that balance will largely be restored, because aquifers dry up, become saline, or become too expensive to exploit. That process is already underway and farmers are abandoning their irrigated land in some places. A non-intervention strategy will reduce groundwater extraction according to Lichtenthaler (2003), as within the next decade a large percentage of farmers will be forced to stop pumping. And livelihoods have to shift out of agriculture. Waves of migration have characterized the history of Yemen. In this sense, irrigation support measures, as envisaged by the proposed programs, may be even counter productive and prolong the process. All this may be doing is buying up time. This view is also confirmed by Ward (2001), who considers interventions as elements of a damage limitation exercise aimed at slowing down the rate of resource depletion, to allow Yemen time to develop patterns of economic activity less dependant on water mining.

Information about the remaining aquifer life is critical from various perspectives: First, where the remaining life is short, is it worth subsidising further in improved irrigation technology (why invest for just a few years' benefit)? Especially if the aquifer is fossil (i.e. not recharged), then what interest is being served by preserving it? Once water for domestic consumption is secured, it may be best to allow the maximum value to be derived for the benefit of local farmers from residual fossil reserves rather than "save" the water for some unspecified future use with a lower present value. Second, where the remaining life is substantial, should priority be given to activities that support collective management or to technical innovations that are in any case profitable—and make pumping more profitable? Whether water is saved or not, the private financial benefits of modern technology are high because of the power savings. As financial incentives are adequate to ensure private investment, the question arises whether such investments should be subsidized? Are such subsidies an appropriate use of public funds? Third, if limited funds are available, should priority be given to those whose livelihoods are most at risk (by supporting non-irrigation investments) or to those whose livelihoods are less threatened?

A change of emphasis should be considered. It is conceivable that new crops, deficit irrigation, an improved extension service, research to optimize irrigation scheduling and so on will find solutions that extend the life of some aquifers. However, these gains are uncertain, will be hard to achieve, and will rarely lead to genuinely sustainable outcomes—rather they will put off the inevitable by a few years, or a decade. Wherever the projected aquifer life is, resources are probably best devoted to the needs of ex-irrigators in the post-irrigation scenario.

The priority is thus not subsidizing improved irrigation technology—which will be introduced by private financing anyway because it is profitable—and may result in marginally faster aquifer depletion, or marginally slower depletion, depending on whether the controls can be enforced.

The question is also not demand management—a low renewable resource, high value of water and limited institutional capacities to monitor and regulate water—make demand unmanageable.

The priority is addressing the needs of the large number of farmers, who will leave the agricultural sector in the coming decade, and to prepare for the new economy (a post-irrigation scenario) that is certainly coming—with or without improved irrigation technology.

First, by means of directing resources towards "buying out" or protecting water rights around major towns and cities so that water for domestic and non-agricultural use is available for the migrants who certainly will be arriving—in need of water to drink, bathe, and cook. Hopefully, industries will develop in this improved environment to provide for their economic needs. To achieve this a good information base is required. Since deep aquifers are complex and difficult to assess, there is currently a lack of accurate information regarding the remaining aquifer life. It is therefore recommended to do a technical study to define the areas required to be reserved for non-agricultural use. This will protect water supplies for the highest value use of all –domestic consumption. Second, provide support (information, advice) to the rural communities that are prepared to address their problems as best they can, and decide how to approach the future.

Elsewhere, the emphasis may be different. If a local community decides to act collectively, based on awareness of the potential aquifer life, it can choose from a number of options: usage can be restricted in order to preserve aquifer life (almost certainly at a cost to current incomes); exploitation can proceed unchecked while the community saves money for the post-irrigation scenario; some farmers could sell their wells (and hence the pumping right) to reduce overall abstractions and provide the seller with funds to move out of agriculture immediately. With proper information, individuals and communities will devise novel approaches to their situation.

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