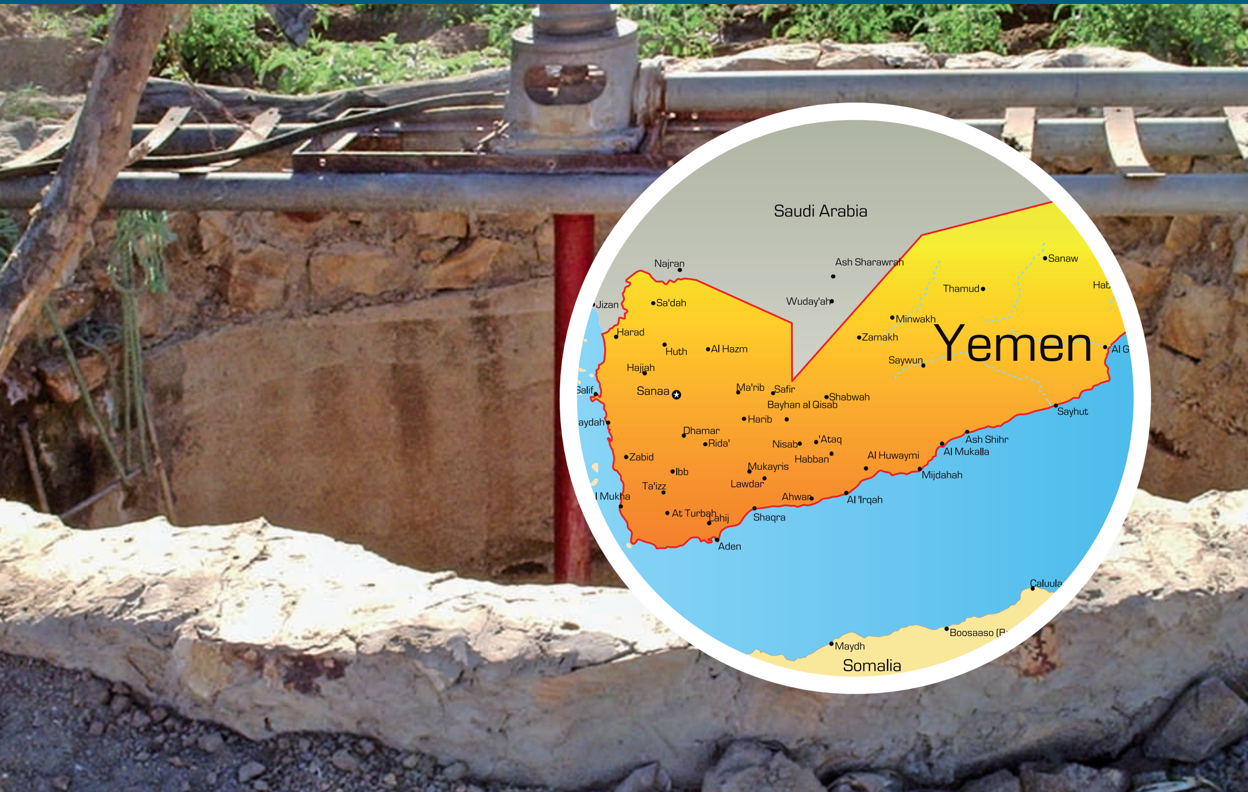
Incentives to reduce groundwater extraction in Yemen



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This report describes the results of the study on options for changing the economic incentive structure for groundwater extraction in Yemen. The study aims to evaluate the potential role of economic incentives to reduce unsustainable irrigation water consumption and to make recommendations for implementing water conservation incentives. It first identifies factors that have triggered groundwater overdraft, then studies farmers' behaviour regarding groundwater extraction on the basis of in-depth interviews with farmers in each of the following three basins - in the Sana'a Basin, the Taiz Basin and Wadi Hadramout. Finally, a number of changes in the incentive structure are evaluated, among others incentives that decrease the profitability of irrigation water use and subsidies on improved irrigation technology. The study shows that although the literature and economic theory suggest that the range of possible interventions is wide (water pricing, metering, water rights, water markets, taxes, subsidies, information, participatory management, et cetera), the range of potentially effective interventions in the Yemeni political context is more limited. The Yemeni case is unique, as there is a close linkage between water and a central socio-economic issue: qat. This adds to the difficulties of implementing or enforcing change.

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Contents

Preface

This report describes the results of the study on incentives to reduce groundwater extraction in Yemen. The objective of this study is to evaluate the potential role of economic incentives to reduce unsustainable water consumption in agriculture and to make recommendations for implementing water conservation incentives. It first identifies factors that have triggered groundwater overdraft, then studies farmers behaviour regarding groundwater extraction on the basis of in-depth interviews with about one hundred farmers in each of the following three areas: the Sana'a Basin, the Taiz Basin and Wadi Hadramout. Finally, a number of changes in the incentive structure are evaluated.

The study is funded by the National Water Resources Authority of Yemen. The duration of the study was 8 months. From October 2007 to June 2008 several visits to Yemen have been undertaken by the international consultants. The results of the study were presented at stakeholder symposia. The feedback obtained from the workshops is included in this report.

The research is conducted by LEI Wageningen UR in the Netherlands in close collaboration with the Water and Environment Centre (WEC) of Sana'a University in Yemen. The authors are grateful for the work done by the support staff of WEC and especially the accurate financial work done by Mr. Al-Aroosi. It was also very pleasant working with Prof. Babaqi (WEC/Director) and with Dr. Naif, who has been a great help in facilitating meetings and helping us to understand the geo-hydrology of the three case study areas. Finally the authors acknowledge the input of Eng. Mahmood Sultan (of NWRA) in preparing for the field work, the input of the field team coordinators of NWRA Eng. Ali Qasem Assayar (Hadramout), Eng. Amin Al-Mushraqi (Sana'a) and Eng. Amer (Taiz) in selecting the sample and the important work done by the various interviewers from NWRA and MAI.

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Prof.dr. R.B.M. Huirne
Director General LEI Wageningen UR

English summary

Until the 1970s, water use in Yemen was sustainable. Agriculture used water resources that are rainfall-dependent and hence, while the country was exceptionally water-short, an approximate annual balance between renewable supply and utilisation was maintained. This changed dramatically with the arrival of tubewell technology that allowed exploitation of water from deep aquifers. Exploitation of this resource is not 'naturally' constrained by annual rainfall, and by now use in many areas is unsustainable.

The objective of this study is to review incentives - primarily economic incentives - that affect demand for water. To achieve this objective, first the literature on the theoretical role of economic instruments in limiting the demand for irrigation water is reviewed. Second, the current economic incentive structure and factors that have triggered groundwater overdraft are studied. This policy analysis is among others based on discussions with government officials in the water sector. Third, farmers behaviour regarding groundwater extraction is studied on the basis of in-depth interviews with about one hundred farmers in each of the following three - rather different - basins: in the Sana'a Basin, the Taiz Basin and Wadi Hadramout. Fourth, a number of changes in the incentive structure are evaluated, among others incentives that decrease the profitability of irrigation water use and subsidies on improved irrigation technology. The usefulness of economic instruments in the context of the three basins is considered. Finally conclusions are drawn and recommendations are made, which have been presented during stakeholder workshops in the three study areas for feedback.

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 a decade. In the 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 Hadhramout, where overdraft is most severe (around seven times recharge), the aquifer is extremely large.

The results of the empirical field work show that the characteristics of farms in Hadramout differ from those in Sana'a and Taiz. In Hadramout farm size is bigger, most farms get as much water as needed and would leave extra water in the well, less farms deepened their well and water is considered to be of a worse quality. In Sana'a the majority of the farms have more than one well and the distribution of wells is strongly bimodal. There are a lot of shallow wells and a lot of deep wells. In Sana'a and especially in Taiz water is more actively traded

than in Hadramout. Hardly any of the farmers is aware of any subsidy received for irrigation. Most farmers grow crops for home consumption on a substantial area of their land. A minority of the farmers is aware that NWRA is responsible for giving licences to dig wells. The majority of the farmers is not a member of a WUA or WUG. They think that god owns the water and that only god knows whether their son or grandson will still have water. They support all kinds of individual, community-based as well as governmental actions that can be taken to reduce water scarcity.

The study shows that although the literature and economic theory suggest that the range of possible interventions is wide (water pricing, metering, water rights, water markets, targeted taxes, subsidies and incentives, information, participatory management, et cetera), the range of potentially effective interventions in the Yemeni political context is far more limited.

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 subsidised diesel and subsidies to improved irrigation technology, which encourages groundwater extraction. The case for and against opening the qat market is, however, 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. The diesel subsidy is a serious drain on the budget - but dealing with that problem will not substantially affect the demand for water (as it is shown in this study that the value of irrigation water is considerably higher than the costs of pumping water). The subsidies to improved irrigation technology are unnecessary, as the private financial incentives to invest in some level of water 'saving' (certainly piped distribution to fields, maybe bubbler and drip) are high because of the profitability for farmers.

Other conventional incentives (water rights, metering, water pricing, controlling pumping, et cetera) have very limited prospects for success as government-administered schemes. For instance, where sustainable water rights are neither defined nor enforced, water markets simply strengthen the pressure of demand on already overexploited resources and are therefore 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 an exceptionally difficult task. Encouraging water markets in the absence of defined rights is wrong. If local groups are persuaded that self-regulation is critical, some forms of regulation may evolve. Again the first priority is the information base that will persuade local groups to act, and help them formulate actions that have the outcomes they desire.

Indirect incentives like education or training for farmers leaving agriculture, will have a role if it is accepted that the agricultural future for a significant number of farmers is bleak.

Regulation has limited prospects for success (again, as a government-administered scheme), since a dominant characteristic of Yemen is its political power structure which comprises an exceptionally strong presidency, and powerful traditional institutions in rural areas that 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. Hence, support to these community actions is recommended in this study.

A key element will be the strong and explicit endorsement of what is required from the other end of the political spectrum, namely the president. Such endorsement would be powerful in supporting actions by rural elites, and would give the government agencies - especially NWRA - added credibility as they pursue their responsibilities.

Persuasion based on information is a universal priority. At the national level, a 'water budget', setting out which activities use how much water would be powerful in mobilising 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 central government (and concomitant strength of local traditional institutions). If local forces are to be mobilised to address local issues, the foundation for their actions will be awareness: how much water do they have; where is it going? Currently the information emphasis is on 'savings'. Whether the advertised savings are correct 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. While frequent references are made to the need to strengthen these (including establishment of an Irrigation Advisory Service), little information is available about messages to be conveyed.

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. In Taiz 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 Hadhramout, while the level of over-abstraction is high, and a fuller understanding of local hydrogeology is needed, the remaining resource is very large.

ملخص

كانت استخدامات المياه في اليمن مستدامة حتى السبعينات، حيث كانت الزراعة تعتمد على مياه الامطار. وعلى الرغم من العجز في المياه في البلد، كان هناك توازن الى حد ما بين المياه المتجددة والاستخدام. ولكن الامر تغير بصورة مأساوية بوصول تقنيات الحفر المتقدمة والتي مكنت من الحفر إلى أعماق كبيرة وسمحت بإستخراج المياه من الخزانات الجوفية العميقة. إن إستخراج هذا المصدر المائي لم يتم تحديده وفقا لكميات مياه الأمطار التي تهطل سنويا، كما أن الإستخدامات الحالية للمياه في المجالات المختلفة غير مستدامة.

إن الهدف من هذه الدراسة هو مراجعة الحوافز – وخصوصا الحوافز الإقتصادية – التي تؤثر على الطلب على المياه. ولتحقيق هذا الهدف فإنه يجب أولا، أن يتم مراجعة ما كتب عن الدور النظري للوسائل الإقتصادية في الحد من الطلب على المياه للري. وثانيا، دراسة تركيبة الحوافز الإقتصادية الحالية والعوامل التي تستهدف إستنزاف المياه الجوفية. وتحليل هذه السياسة والتي هي من ضمن امور أخرى تعتمد على النقاشات مع مسئولي قطاع المياه في الحكومة. ثالثا، دراسة ممارسات المزارعين فيما يخص استخلاص المياه الجوفية من خلال المقابلات المكثفة والمتعمقة والتي تمت مع حوالي مأة مزارع في كل من الأحواض الثلاثة المختلفة: حوض صنعاء، حوض تعز وحوض حضرموت. رابعا، تقييم عدد من التغيرات في تركيبة الحوافز الإقتصادية من ضمن الحوافز الأخرى التي تقلل الربحية لإستخدام مياه الري والدعم المقدم لتقنيات الري المحسنة. وأعتبار فائدة الوسائل الإقتصادية في محتوى الأحواض الثلاثة. وأخيراً فقد تم صياغة الإستنتاجات وعمل التوصيات في المناطق الثلاث التي شملتها الدراسة وتم تقديمها خلال ورشة العمل بحضور الجهات ذات العلاقة.

إن استنزاف المياه في حوض صنعاً يتم بمعدل عالي، (حوالي أربعة إلى خمسة أضعاف التغذية) ويقدر العمر المتبقي للحوض بما يقارب عقد من الزمان. بينما حوض تعز، حيث الإستنزاف أقل حدة (السحب يقدر بضعف التغذية)، فإن مستوى المياه الجوفية في هبوط مستمر كما إن العمر المتبقي للخزان الجوفي غير واضح. أما في وادي حضرموت، حيث الاستنزاف أكثر حدة من الحوضين السابقين (حوالي سبعة أضعاف التغذية)، يعتبر الخزان الجوفي واسع جدا.

بينت النتائج للأعمال الحقلية التجريبية أن الخصائص للمزارع في حضرموت تختلف عن الخصائص للمزارع في كل من صنعاء وتعز. وحيث أن حجم المزرعة في حضرموت اكبر، فإن معظم المزارع تحصل على المياه بالقدر الذي تحتاجه وتترك كميات إضافية في البئر، كما أن المزارع التي تعمق أبارها أقل ونوعية مياهها سيئة. وفي صنعاء غالبية المزارع لديها أكثر من بئر وتوزيع الابار يتم بصورة عشوائية. كما أن هناك آبار سطحية كثيرة وآبار عميقة كثيرة ايضا. وقد لوحظ أن تجارة المياه أكثر فعالية في كل من صنعاء وتعز، الا انها بشكل اوسع في تعز عما هو عليه الحال في حضرموت. ولوحظ أيضا أن المزارعين لا يوجد لديهم أي علم عن وجود أي دعم للري. ومعظم المزارعين يزرعون محاصيل لإستخداماتهم وفي مساحات كبيرة من أراضيهم. والقليل من المزارعين يعرفون بأن الهيئة العامة للموارد المائية هي المسئولة عن إصدار التراخيص لحفر الابار. كما أن غالبية المزارعين ليسوا أعضاء في إتحاد مستخدمي المياه أو جمعية مستخدمي المياه. وهم يعتقدون أن الله يمتلك المياه والله فقط يعلم ما إذا كان أبنائهم واحفادهم سيظل لديهم مياه. وهم يدعمون جميع الإجراءات اللازمة لتقليل ندرة المياه سواء الفردية أوالتي تصدر عن المجتمع وكذلك الحكومية.

وقد أوضحت الدراسة أنه بالرغم مما كتب وذكر في نظرية الاقتصاد والتي تقترح أن مدى التدخلات الممكنة واسع (تسعيرة المياه، قياس كمية المياه، حقوق المياه، أسواق المياه، الضرائب المستهدفة، الدعم والحوافز، المعلومات، الإدارة التشاركية، إلخ..)، إلا أن مدى التدخلات الفعالة الممكنة في المحتوى السياسي اليمني محدودة إلى أدنى حد.

إن الحوافز المباشرة الحالية تتكون، وبأهمية عظمى، من حماية سوق القات (بحيث تكون الاسعار المحلية أعلى مما هو عليه الحال في حالة تحرير تجارته)، الدعم العالي للديزل، ودعم تقنيات

الري المحسنة، وكلها تشجع على استخراج المياه الجوفية. إن قضية مع وضد فتح سوق القات، على أي حال، ليست بالأمر السهل. إجتماعيا سيكون الأثر سلبيا (زيادة الإستهلاك)، طبيا سيكون الأثر ايجابيا (أقل تعرض للمبيدات)، إقتصاديا، سيكون الأثر سلبيا ما لم يتم تحديد بديل استخدام مناسب. إن دعم الديزل يعتبر تسرب خطير في الموازنة- ولكن التعامل مع المشكلة لن يؤثر بشكل جوهري على الطلب على المياه (كما تم توضيحه في هذه الدراسة من أن قيمة مياه الري تعتبر أعلى من تكاليف ضخ المياه). إن دعم تقنيات الري المحسنة غير ضرورية، كما ان الحوافز المالية الخاصة للاستثمار في بعض مستوى "توفير" المياه (بالتأكيد التوزيع بالمواسير إلى الحقول، قد يكون الري الفقاعي والتنقيط) عالية بسبب الربحية للمزارعين.

والحوافز التقليدية الأخرى (حقوق المياه، قياس كمية المياه، تسعيرة المياه، التحكم في الضخ، إلخ..) نجاحها محدود كونها أنظمة تديرها الحكومة. إن الحقوق المائية المستدامة غير محددة ولا مطبقة بشكل محكم، وأسواق المياه ببساطة تقوي الضغط للطلب على الموارد المائية التي هي مستنزفة أصلا ولهذا تكون ذات أثر سلبي على استدامة استخدام الموارد. كما أن تحديد الحقوق المائية حاليا يتم بناء على الاستخدام التاريخي، وأحقية استخراج مايقع تحت أرض أي فرد. وبتحويل هذا، عن طريق القطاع الرسمي، إلى إستحقاق كمي، يفرض بالنظام والقانون هي مهمة في غاية الصعوبة. وإنه لمن الخطأ تشجيع أسواق المياه في غياب حقوق مياه محددة. واذا إقتنعت المجموعات المحلية بأهمية التنظيم الذاتي، فإن بعض أشكال التنظيم يمكن أن ينشأ ويتطور. ومرة أخرى الأولية الأولى هي قاعدة المعلومات التي ستقنع المجموعات المحلية باتخاذ الأجراءات، وتساعدهم على صياغة الاجراءات والتي سيكون لها النتائج التي يرغبون بها.

إن الحوافز غير المباشرة مثل التعليم او التدريب للمزارعين الذين يتركون الزراعة، سيكون لها دور اذا تم التسليم بأن مستقبل الزراعة لعدد كبير من المزارعين قاتم.

إن الرقابة لديها توقعات محدودة للنجاح، (مثل النظام الذي يدار من قبل الحكومة)، حيث أن الخاصية السائدة لليمن هي قوة تركيبتها السياسية التي تتكون من رئاسة قوية وبصورة إستثنائية، ومؤسسات تقليدية قوية في المناطق الريفية والتي تتميز بتأثير كبير في الحياة اليومية لمعظم المجتمعات الزراعية. وبين هذين الطرفين، فإن المنظمات الحكومية تكون ضعيفة: كما أن القوانين "المركزية" تحد من او تنظم تصرفات الناس المحليين ويكون لها أثر ضئيل مالم تقتنع النخب الريفية عن طريق الحوار وتصبح جزء من العملية التنفيذية. ولهذا فهذه الدراسة توصي بدعم تصرفات المجتمع.

إن هناك عنصر رئيسي والذي سيكون قويا وتصديقا واضحا لما هو مطلوب من الطرف الاخر للطيف السياسي، والمقصود هنا الرئيس، مثل هذه المصادقة سيكون لها قوة في دعم تصرفات النخب الريفية، وستعطي المنظمات الحكومية – خصوصا الهيئة العامة للموارد المائية – مصداقية إضافية كونهم يتابعون مسئولياتهم.

أن الاقتناع بناء على المعلومات هي أولوية شاملة. على المستوى الوطني "الموازنة المائية" والتي تضع أي الأنشطة تستخدم كم من المياه ستكون لها القوة في تحفيز الارادة السياسية لتناول مسألة السحب الجائر. محليا, المعلومات عن عمر الخزان الجوفي المتوقع سيكون مؤثرا في دعم الؤسسات التقليدية. وهذا خصوصا ما هو عليه الحال عندما يكون هناك ضعف نسبي للحكومة المركزية (ويرافق ذلك قوة المؤسسات التقليدية). اذا تم استنفار القوى المحلية لتناول الامور المحلية, فان التوعية هي الاساس لتصرفاتهم, كم لديهم من المياه؟, أين تذهب هذه المياه؟ حاليا المعلومات تؤكد على "توفير المياه". بغض النظر عن ما اذا كان الوفر المعلن للمياه صحيحا أم لا وهذه قضية, وأمر مهم للغاية وهو ما اذا كان الوفر للمياه سيفضي الى طريق يؤدي الى مستقبل مختلف تماما. على مستوى المزرعة يتم نقل المعلومات عن طريق خدمات التوعية. بينما يتم تكرار الاشارة الى الحاجة لتقوية هذا الأمر (بما في ذلك تأسيس خدمة استشارية للري) المعلومات المتوفرة عن الرسائل التي يجب أن تنقل قليلة.

إن لإختلاف المواقع التي أجريت فيها الدراسة كان لها الاثر في تحديد الاولويات. إن الاولوية في صنعاء هي لحماية امدادات المياه للاستخدام ذات المردود العالي - للاستخدام المنزلي. هذه الاولوية تبدو أهميتها نظرا لان الذين يتركون أراضيهم سيهاجرون الى المدن. وبما انه لا يوجد حاليا

معلومات دقيقة عن العمر المتبقي للخزان الجوفي, فيوصى بعمل دراسة فنية للمناطق حول صنعاء والتي يجب أن لا يتم فيها أي نشاط زراعي. كما أن الاولوية القصوى في تعز هي لتوفير معلومات عن الكمية الانتاجية المستدامة للخزان الجوفي "المحلي", ما هي آليات التغذية؟, هل هناك مناطق يتم فيها استنزاف كلي للمياه في المستقبل المنظور؟.

أما في حضرموت, حيث مستوى السحب عالي, هناك حاجة ماسة لمعرفة الهيدرولوجيا المحلية, وبالرغم من ذلك فالموارد المائية المتبقية كثيرة جدا.

1 Introduction

Until the 1970s, water use in Yemen was sustainable. Agriculture used direct rainfall, spate flows in rivers following rainfall events, flows from springs, and exploitation of the shallow aquifers. All these sources are rainfall-dependent and consequently, while the country was exceptionally water-short, an approximate annual balance between renewable supply and utilisation was maintained.

This changed dramatically with the arrival of tubewell technology that allowed exploitation of water from deep aquifers whose recharge characteristics are much more complex than the shallow aquifers, and indeed whose water content often comprises infiltration from many years previously. Exploitation of this resource is not 'naturally' constrained to equal by annual rainfall, and by now use in many areas, including those covered by this study, is unsustainable. Dependence on this resource (which is now the dominant situation in many areas) has socio-economic implications for society generally, and in particular for those whose livelihoods are based on irrigated agriculture.

The current economic incentive structure seems to encourage instead of discourage groundwater extraction. It consists most importantly of a protected qat market (so that domestic prices are higher than would be the case under free trade); highly subsidised diesel; and subsidies to improved irrigation technology.

According to the literature and economic theory there is a wide range of possible changes in the economic incentive structure (water pricing, metering, water rights, water markets, targeted taxes, subsidies and incentives, information, participatory management, et cetera). It is, however, important to understand the potential effectiveness (in terms of water conservation) and (socio-economic) implications of such interventions in the Yemeni context.

This study therefore aims to evaluate the potential role of economic incentives to reduce unsustainable irrigation water consumption by 1) identifying factors that are driving groundwater overdraft in Yemen; 2) identifying realistic incentives to motivate the agricultural sector in reducing its groundwater extraction from rapidly depleting aquifers, and 3) making recommendations for implementing water conservation incentives.

To accomplish this, the following six activities have been undertaken: literature review, policy analysis, empirical field work, evaluation, recommendations and presentation/workshop.

So first the international literature on the theoretical role of economic instruments in limiting the demand for irrigation water is reviewed (chapter 2), then their usefulness in the context of three study areas: the Sana'a Basin, the Taiz Basin and Wadi Hadramout is considered.

The situation is not uniform: the three study areas present three distinct scenarios:

- in the Sana'a Basin, where the overdraft is substantial (estimated to be around four to five times recharge), the remaining aquifer life is thought to be around a decade;
- in the 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 Hadhramout, where overdraft is most severe (around seven times recharge), the aquifer is extremely large.

The technical approach to all three situations is, however, common: to save water through improved technology and better irrigation management, and to seek higher value crops that maintain or enhance farm incomes. In other words, improve the 'crop' and reduce the 'drop'.

In chapter 3, the major government policy decisions which have affected the incentive structure facing farmers are summarised. A distinction is made between developments in the agricultural sector and in the water sector as well as macroeconomic developments. The policy analysis is among others based on discussions with government officials in the water sector.

The results of the empirical field work are presented in chapter 4, which aims at a better understanding of farmers' behaviour regarding groundwater extraction. Information is collected on the basis of in-depth interviews with about one hundred farmers in each case study area.

A number of changes in the incentive structure are evaluated in chapter 5, such as incentives that decrease the profitability of irrigation water and subsidies on improved irrigation technology. Special attention is paid in the evaluation to differences between the study areas. In some areas there is a close linkage between water and a central socio-economic issue, qat, which adds to the difficulties of implementing or enforcing change.

Finally, conclusions and recommendations for implementing water conservation incentives have been formulated (chapter 6) and presented at three workshops in the case study areas. The feed-back from the workshops as well as the comments from the steering committee on the interim progress report have been incorporated in the various chapters of this report.

2 Literature Review

2.1 Introduction

Internationally, as competition for water has increased, demand has exceeded sustainable supply in many countries, leading to deteriorating eco-systems, drying rivers and declining aquifers. In recent years, the concept of demand management has gained popularity. The approach proposed is that instead of continuously increasing the supply of water through new dams, wells and other facilities, attention should be paid to the demand side by discouraging waste and encouraging reallocation of water from lower to higher value uses. The Dublin Principles (the fourth of which is *Water has an economic value in all its competing uses and should be recognised as an economic good*) encouraged the idea.

This chapter is a review of international experience on the theoretical and practical role of economic instruments in limiting the demand for irrigation water.

Yemen is far from unique in facing excessive water use and aquifer depletion. Mexico, the United States, Spain, Morocco, Tunisia, Libya, Israel, Turkey, Pakistan, India, Bangladesh, and China, and many other countries (or significant areas within countries) could be added, but it is clear that size, wealth and to a degree even relative resource abundance are no bar to excessive water demand and aquifer management. In one respect the Yemeni case is unique: it involves a close linkage between its central resource issue (water) and a central socio-economic issue (qat). This adds to the political and social complexity of the issue - and indeed the difficulties of implementing, encouraging or enforcing change.

This review is in two parts: the first part examines the evidence that interventions that decrease the profitability of water use can reduce significantly the demand for water. The second part examines the role of technology in reducing water consumption, and hence the contribution that subsidies to technology may have in balancing supply and demand of water.

2.2 Interventions to decrease profitability

The vast majority of the literature on demand management for irrigation water relates to surface water. The reason for the dominance of surface water in the literature is most probably because a principle concern has been that surface irrigation water is under-priced because governments have failed to recover the full costs of the service from the beneficiaries. Consequently, general taxes are required to ensure financial sustainability. Most groundwater irrigation is privately owned and therefore cost recovery is less of a concern, but in both surface and groundwater, demand often exceeds supply so that economic instruments are of relevance to the objective of 'demand management'.

The most comprehensive recent general review of international experience is that of Bosworth et al. (2002) undertaken to assess the lessons learnt from existing experience around the world and to make full use of existing thinking on the subject. Completed in October 2002, the review covered almost 50 countries.

This review (and the associated guidelines for irrigation service charges, Cornish et al., 2003) were careful to clarify terminology. The terms charge, price, cost and value are commonly used interchangeably. To avoid confusion, the terminology used in the rest of this summary, and throughout the Guidelines is consistently based on the following definitions:

- *irrigation service charge*: the total payment made by a user for an irrigation service. It may comprise fixed elements (e.g. USD20 per hectare) plus variable elements (e.g. USD1 per 1,000m^3 of water). In this example, if a user with 1ha took 10,000m^3 under the above charging system, the charge would be USD30;
- *price* in the above example, the average price of water would be the total charge divided by the total quantity of water received (USD30/10,000 = USD0.03 per m^3). The marginal price would be the cost of an additional unit of water (USD1/1,000m^3);
- *cost of the irrigation service*: the expenses incurred by the supplying agency in providing the service. Precise definitions depend on local rules, but typically include operation, maintenance, staff and fuel costs, plus some elements of replacement costs and amortisation of capital;
- *value of water:* incremental income received by the farmer as a result of irrigation services, divided by the quantity of irrigation water used.

These definitions (aside from ensuring clarity in defining what is meant by 'price', 'cost', et cetera) are of particular relevance to demand management: clearly if the value of water to a farmer - the incremental income that he derives from its use - is significantly higher than the cost of the water, so that he derives a substantial profit from its use, then demand will be high.

The main conclusions of the Bosworth report are worth extensive quotation, as they bear directly on the Yemeni situation, and embody experiences from many countries.

- *Volumetric water pricing or tradable water allocations are used where the objective is to reduce water demand in the agricultural sector. However, 'there is little practical evidence from the field to support the view that volumetric pricing changes farmers' water demand patterns.'*
- *Even in Jordan, Israel and Morocco, countries facing extreme water scarcity, the aim of water pricing is to recover service delivery costs. 'Volumetric water allocations, rather than water price, are used to ensure that other sector needs are met.'*
- *In all of these countries water is priced on a volumetric or approximate volumetric basis to indicate its value to users and discourage profligate use, 'but there is no attempt to use water pricing to achieve the balance between supply and the demand' of competing sectors.*
- *Water markets and tradable water rights could theoretically be more effective than water pricing as a means of achieving allocation efficiency. However, formal water markets may potentially lead to inequitable access to water resources and disadvantage poor farmers who lack resources to buy water.*
- *Unless safeguards are provided there is a risk that water will flow increasingly according to purchasing power.*
- *Formal markets for large transactions between sectors require a well-defined legal and regulatory framework and are mainly found in developed countries, with Australia and Spain being widely cited examples.*
- *'The price response to volumetric water charging is widely shown to be minimal.' Current prices are well below the range where water saving is a significant financial consideration for the farmer, so prices must be raised dramatically and generally well beyond estimates of the cost of the service, if volumetric charges are to have a significant impact on demand.*
- *Water scarcity will continue to increase, leading to more competition for water between agricultural, municipal and industrial sectors. The agricultural sector is seen as wasteful in its use of water when, on large irrigation*

schemes with open channel conveyance, as much as 70% of water diverted from a source fails to arrive at the crop.

However, three important points must be made concerning these 'losses:'

- *'lost' water often returns to an aquifer or river and is therefore not lost to downstream users.' It is only lost if it deteriorates in quality or drains to a sink from which it cannot be economically recovered. Consequently, switching to 'high tech' irrigation methods such as drip or sprinkler may not result in any overall savings of water if the previous losses were recaptured by others;*
- *the farmers' in-field management of water accounts for less than half of the losses. More than half the total losses occur in the conveyance and distribution canals. As individual farmers have no control of this infrastructure, pricing incentives cannot affect these losses;*
- *withdrawal of water, which then returns to a river or an aquifer, will increase the cost of service delivery but may not affect overall levels of water scarcity;*
- *Japan, France, Australia, Spain and the Netherlands stand out as achieving full recovery of annual O&M costs and some recovery of capital costs.*

However, in the overwhelming number of cases, water charging is not covering even annual O&M costs. The literature refers to various institutional and political factors that hamper full cost recovery in different countries, including:

  - *the lack of political will to impose higher costs on farmers;*
  - *practical and political difficulties associated with enforcement of pricing policies;*
  - *where volumetric charging is applied to limit consumption, delivery must be measured and controlled to the individual user.*
- *the introduction of a water charging policy should not be viewed as a 'silver bullet' that can deliver all. In the case of demand management the literature again indicates that pricing is only one element. Legally recognised water rights and allocations and the use of tradable water rights are other common elements in such a programme;*
- *there is much written material on water pricing but far less on effective collection mechanisms. In many countries the issue is not one of how to determine the level of water prices, but how to implement and enforce any pricing policy. Without due consideration of the revenue collection and enforcement systems, policy makers may design pricing policies that are theoretically sound but practically unmanageable.*

An additional point made in this review is that while there is an extensive academic literature demonstrating the linkage between the value and price of water and demand, this is primarily based on modelling exercises rather than field experience.

Cornish et al. (2004), summarise information on water charges from 50 countries including surface and groundwater schemes, and finds only two (Spain and Israel) where the volumetric charge for water exceeds USD0.1 per m^3. In both cases these are groundwater-based schemes. These data relate to water charges in government schemes. Data from privately owned groundwater sources are rare. The report mentions Pakistan (USD0.17 per m^3) and Yemen (USD0.02-1.46 per m^3). This last price is the highest reported price for irrigation water in the review.

The general conclusions from these two reviews of international experience are that prices of water in irrigation systems are generally considerably lower than required even to recover operating costs, and are far below the levels required to have significant impact on demand for irrigation water. Moreover, increasing the price of water (or decreasing the price of irrigated crops) is likely to be politically sensitive, and difficult to implement. For individual wells (as distinct from publically operated surface irrigation projects) the difficulties in monitoring use and relating the charge to the volume pumped are of course far higher.

Other sources offer additional information. The joint World Bank/GWP GM-MATE programme offers advice on issues related to groundwater management. It is comprehensive and clear:

Sustainable groundwater utilisation will require actions to be taken at two different administrative levels:

- macro-economic policy interventions - because groundwater demand is strongly influenced by national subsidies (on water well drilling, electrical energy, diesel fuel, food crops) and they affect the size of existing groundwater-based agriculture and the rate of transition to less water-dependent livelihoods;
- local-level management measures - to create effective institutional arrangements (empowered government agency, adequate legal framework, user awareness/participation, groundwater abstraction charging, land-use constraints) to regulate, protect and monitor groundwater resources.

The Briefing Note Series addresses both of these levels, but puts greater emphasis on the latter in the belief that (especially in water-scarce and/or densely-populated regions) sooner or later effective local management arrangements will have to be put in place.

According to GW-MATE[1] the approach taken to groundwater management at any moment in time will depend on the following factors:

- the size and complexity of the groundwater resource;
- the degree of climatic aridity and the rate of aquifer recharge and resource renewal;
- the scale of groundwater abstraction and the number and types of groundwater users;
- the ecological role and environmental services dependent upon groundwater;
- the susceptibility and vulnerability of the aquifer system to degradation;
- natural groundwater quality concerns (trace element hazards and saline water presence).

The focus of this review is on economic instruments and policies, but this list of 'relevant factors' highlights the extreme nature of the situation faced in Yemen.

Table 2.1 **Price, cost and value of water (USD/m³) in selected irrigation areas**

	Price paid (USD/m³)	Price/Cost Ratio a)	O&M Cost (USD/m³)	Price/Value Ratio a)	Value of water (USD/m³)
Kemry (Egypt)	0.0004	1:25	0.010	1:200	0.08
Haryana (India)	0.0005	1:2.6	0.0013	1:80	0.04
Tadla (Morocco)	0.0200	1:0.8	0.017	1:5	0.10
Brantas (Indonesia)	0.0002	1:5.0	0.001	1:200	0.04
Crimea (Ukraine)	0.0020	1:6.0	0.012	1:55	0.11

a) Where the Price/Cost ratio exceeds 1, costs are not recovered; where the Price/Value ration is high, price has little impact on demand.

[1] Sustainable Groundwater Management: Concepts and tools. Series overview. (GW - MATE, 2002-6).

Hellegers and Perry's study of the literature and a number of case studies confirms particularly the fact that prices set to recover operational costs are already rare, and that the extra price that would be required to induce farmers to modify their consumption of water are generally beyond the politically feasible level. Table 2.1 above summarises the ratios between the cost, price and value of water in a number of countries/areas.

GW-MATE note 7 specifically addresses the role of economic instruments, making the important initial points that groundwater presents some special difficulties: assessing and monitoring resource availability is complex and expensive (aquifers are complex and differentiated; use is highly decentralised); groundwater is invisible to the public; and the time lag between overdraft and measurable impact may be extremely long.

The note refers to the problem that the user of groundwater generally pays only part of the economic cost. Where the resource is scarce, current usage is at the expense either of alternative uses or future uses. The cost to the user is consequently too low and induces over-use. This in turn leads to the 'tragedy of the commons' (Hardin, 1968) where it is in each *individual's* interest to exploit the resource as quickly as possible, which is contrary to the *collective* interest of sustainable use for current and future generations.

The note then summarises the economic instruments available to influence abstraction:

- *direct pricing through abstraction fees - difficult because wells are widely dispersed and rarely metered, and conditions vary locally;*
- *indirect pricing through energy tariffs - in order to offset impacts on poor, may require lump-sum payments. This is complex to administer;*
- *groundwater markets require that water rights based on sustainable yields are in place and enforced*[1]*; may have negative impacts on the poor as water is transferred to higher value uses; water rights need to be specified in relation to historic entitlements and local aquifer conditions;*
- *modification of agricultural and food trade policies - can influence demand for water by making water-intensive crops less attractive; may also restrict*

[1] There is considerable confusion in the literature about what constitutes a groundwater market. It is commonly assumed that farmers who can purchase water from one of several local pump owners are participating in a water market (Meinzen-Dick, 1997). This is entirely misleading - they are in fact participating is a market for pumping services: usually *all* the pump owners are pumping from the same aquifer. There is no market in alternative sources of water. By contrast in Yemen, when water is purchased from tankers, this is often a genuine water market because they get their water from different sources. This means that each 'source' is exposed to its highest-value use - further increasing demand and abstraction.

potential returns from groundwater by preventing export of high value crops. The impact of this is on the one hand to reduce the demand for water (positive impact) while on the other hand reducing the benefits derived from using the scarce resource (negative impact);

- *subsidies to encourage real water saving measures - need to be carefully appraised to ensure real savings.*

Where economic instruments are proposed, it is essential to ensure that enforcement is feasible.

The literature described above is primarily aimed at practitioners, and identifies issues and options in the application of economic instruments to achieve objectives that include demand management. There is an additional wide literature based on modelling, to demonstrate that indeed as the price of water increases farmers will change to different crops and try to limit water consumption. While academically interesting, the relevance of such work (aside from importantly demonstrating the directions of change) is severely limited by the extensive list of political and technical difficulties with implementation, impacts on farm incomes, and real uncertainties with the actual resource impacts of revised economic incentives.

In sum, while economic instruments that change the incentive structure at the farm level can *influence* farmers to use less water and to use it more productively, such interventions are not the basis for bringing about a balance between supply and demand.

This conclusion is supported by the practical examples quoted in the text above as well as a review of the fifteen case studies that are provided in parallel with the GW-MATE 'Concepts and Tools' series in its 'Profiles[1]' series.

The Profiles cover case studies from Thailand, Yemen, Paraguay, Argentina, Brazil, Kenya, Venezuela, China, Mexico, India, Nepal, a number of multi-country aquifers, and sub-Saharan Africa.

In only three of these studies (India, China, Mexico) were economic incentives mentioned as a direct vehicle for affecting demand - despite the prominence given to pricing elsewhere - in each case through increasing the cost of power. In Yemen, the use of subsidies to encourage improved irrigation technology is mentioned.

A more common issue raised in these profiles is the need for participation by local stakeholders and water users to understand the problems they face, to reach jointly acceptable management plans, and perhaps most importantly to

[1] GW-MATE Profiles GW-MATE website, viewed 22 January 2008.

enforce agreements through local peer pressure. In the Tamil Nadu (Indian) case study, reference is made to monitoring groundwater levels and taking local decisions on seasonal use based on water availability.

In most cases, however, both in the GW-MATE cases and elsewhere in the literature, definition of water rights - based on sustainable average availability of water - is seen as the key intervention to control demand.

The reduced income to farmers resulting from inducing a specific reduction in water use through pricing water was compared to the income reduction from the same reduction by a direct quota was explored in Perry (1996) for Egypt. It was found that the water price increase required to induce a 15% fall in water demand would result in a 40% fall in farm income while a direct reduction in availability of water by 15% (equivalent to a reduced water right) would lead to a fall of less than 15% in farm income.

Terrink and Nakashima (1993) give a resume of water supply pricing in California. It is striking that water pricing is only perceived as a mechanism to recover costs - there are no practical examples of it being used as a demand management tool.

Israel's water supply is derived from three principal sources, the coastal aquifer, the inland, mountain aquifer and the sea of Galilee. In addition to these three main sources there are a further five, locally important aquifers. All of these sources have been over-exploited, with annual withdrawals exceeding recharge. The pragmatic response to this has been for the Water Commission Agency to cut back allocations to the agricultural sector. Ironically, despite this simple and practical response, Becker and Levine (2002) argue the theoretical case in support of using water pricing to reduce agricultural demand rather than further reliance on this apparently simple and transparent mechanism.

For the Yemen, Ward (2000) believes that combining an increase in water prices with the introduction of irrigation efficiency measures, is a viable option. He argues that if water pricing encourages farmers to use water more efficiently, they will then be more likely to adopt water-saving technologies. Investment and research into water conservation techniques would complement a water pricing strategy, with support from government and donors.

Ward comments that 'more efficient irrigation could help relieve pressure on groundwater resources and restore, or even increase, farm incomes' (p.393).[1]

Lichtenthaeler (2003) has written an exceptionally detailed review of the Sa'dah Basin, which faces water scarcity and over-use comparable (but perhaps further advanced) to other parts of Yemen. His analysis of the policy background is referenced elsewhere in this report. For the purposes of this section, his key conclusion is that emerging actions to respond to the crisis centre on the capacity of local groups to learn lessons from their problems and devise local procedures to control exploitation of water.

Conclusions from experience of demand management through profit reducing measures

Interventions that raise the price paid by farmers for water, or reduce the value of water through changes to input costs or price of products have been of considerable interest recently, as a means of *demand management*. Such interventions are of particular relevance to groundwater, where control of over-abstraction in thousands of individual wells by a central agency is unrealistic.

However, *demand management* can be interpreted at two levels - first, as an effective incentive to *reduce* demand, and second as a means of achieving a *balance between demand and supply*. Pricing and other economic instruments will certainly achieve the first objective - at some cost to farm incomes, but there are consequently no examples of direct water pricing being used to meet demand management objectives in the full sense of bringing demand down to the sustainable supply level.

This is a critically important conclusion, because the implication is that *additional* measures - typically the definition of water rights consistent with resource availability - are required for full demand management. Since the interventions required to raise the price of water (or lower its value) will be unpopular with farmers, following this with a programme of reducing access to the resource will be even more sensitive.

However, while economic interventions to reduce the incentives to use groundwater will be unpopular because of the impact on farm incomes, such in-

[1] This is the theory. However, in Jordan, investment in water efficient technology has not led to any measurable water saving. Despite wide-scale adoption of drip technology, application efficiencies for irrigation water have not improved significantly and distribution efficiency remains low. Farmers perceive the JVA's water supply to be unreliable. Hence, when water is available they tend to over - irrigate to store water in the soil, a situation that leads to greater losses (cited in Huppert and Urban, 1999).

terventions are generally within the powers of central government - while control of abstraction at the individual well level is essentially impossible.

If input and output incentives cannot achieve a balance between demand and sustainable supply, there are two options - either the balance is achieved by default as wells dry up, or collective actions at the local level must enforce reductions in use.

Finally, the impact of economic interventions that reduce the profitability of water use is inevitably to reduce farm incomes, and if substantial reductions in use must be induced then the income effects will in turn be substantial. Given that many of the farmers affected are poor, compensation schemes would need consideration.

2.3 Technical interventions to decrease consumption

The alternative strategy of subsidising 'water saving' technologies is also assessed in the literature, with critical attention paid to the real hydrological impacts of such changes - whether the reduced 'losses' are indeed lost or are available for reuse from an aquifer or downstream in a basin.

Irrigation is widely seen as a wasteful, low value use of water. The observed efficiency of surface irrigation systems is in the order of 40%, while it is claimed that efficiencies of double this figure are feasible. Efficiency is here defined as the ratio of the water used by the plant to the water delivered to the system (project, canal, or field). Implicitly, very large quantities of water can be saved by improved technology.

Recently, however, there has been an extensive debate about the terminology of this analysis. A simple example illustrates the confusion: in Egypt, on-farm efficiency is assessed at 40% (World Bank, Irrigation Improvement Project). Yet of the 55.5BCM of water entering Egypt each year from Sudan, only about 10BCM go to the Mediterranean. Egypt has virtually no rainfall or groundwater, and irrigation dominates water use. If irrigation is 'wasting' 60% of the water at the field level, why is only 20% of available water flowing to the sea? The answer, of course is that losses at field level flow to drains, back to the Nile, and are diverted for use in downstream canals. Groundwater is no different - indeed it is generally the case that excess irrigation application infiltrate back into the water table - but in the case of groundwater there are often additional complexities. These issues have been alluded to in literature already referred to above.

Bosworth et al. (2002) note (emphasis added):

- *water scarcity will continue to increase, leading to more competition for water between agricultural, municipal Water scarcity will continue to increase, leading to more competition for water between agricultural, municipal and industrial sectors. The agricultural sector is seen as wasteful in its use of water when, on large irrigation schemes with open channel conveyance, as much as 70% of water diverted from a source fails to arrive at the crop.* However, three important points must be made concerning these 'losses':
- *'lost' water often returns to an aquifer or river and is therefore not lost to downstream users.* It is only lost if it deteriorates in quality or drains to a sink from which it cannot be economically recovered. Consequently, switching to 'high tech' irrigation methods such as drip or sprinkler may not result in any overall savings of water if the previous losses were recaptured by others;
- *the farmers' in-field management of water accounts for less than half of the losses*. More than half the total losses occur in the conveyance and distribution canals. As individual farmers have no control of this infrastructure, pricing incentives cannot affect these losses.

These points are echoed in GW-MATE Note 3[1] (emphasis added):

- it is always essential to address the issue of constraining demand for groundwater abstraction, since this will normally contribute more to achieving the groundwater balance, and in more arid and densely-populated areas will always be required in the longer run. The *concept of real water savings* is critical in this regard. These savings include only reductions in evaporation (that is consumptive use) and in loss to saline water bodies, but not those reductions which would have generated aquifer recharge;
- in some instances improvements in irrigation water-use efficiency while generating improvements in water-use productivity and farmer incomes, lead to deterioration in the groundwater resources balance as a result of;
- substituting increased field-level evaporation/evapotranspiration (in spray irrigation) for major groundwater irrigation - return flows (occurring in flood irrigation);
- making feasible the expansion of irrigation command and the area actually under cultivation (due to the capacity of pressurised water delivery);

[1] Sustainable Groundwater Management: Concepts and tools. Groundwater Management Strategies. (GW-MATE, 2002 - 6).

- facilitating the introduction of higher-value crops, which *make it viable for farmers to deepen wells* and to pump groundwater against greater hydraulic heads.

The points made here can be illustrated graphically by figure 2.1, following Hellegers and Perry (2004).

The 'Use' demand for water is the quantity that the farmer pumps from the aquifer. The value the farmer derives from that use is related to the consumption of that water in productive plant transpiration. Under Technology 1, at a given price P_1, the 'Use' demand is Q_1 while consumption is C_1. The difference between Q_1 and C_1 are the 'Losses' to non-beneficial evaporation, runoff, and infiltration of excess applied water. If the price of water increases to P_2, Use demand falls to Q_2 and Consumption falls to $C_{2,1}$. However, if the farmer then decides that should reduce his losses and invests in technology 2, then while Use demand remains at Q_2, consumption *increases* to $C_{2,2}$. If the 'losses' were indeed non-recoverable all well and good; if the losses were contributing to aquifer recharge, then the net overdraft will increase as a result of the 'improvement'. Further, in relation to second and third points in the GW-MATE quote, above, the farmer will with the new technology be able to afford to pump water from even deeper, because the beneficial component of a unit of 'use' has been increased.[1]

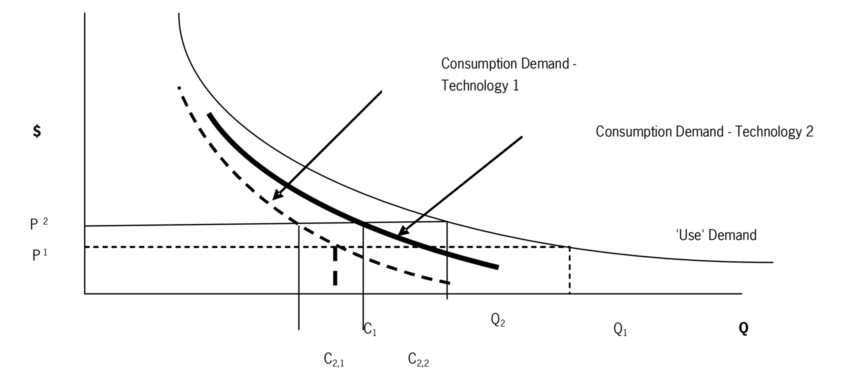
The implications of these points are that interventions in technology or the incentive structure must be carefully assessed in the relevant hydro-geological context before conclusions are drawn about the impact on an aquifer.

Meanwhile, countries facing water scarcity face difficult (and expensive) decisions regarding irrigation technology. The basis for meaningful discussion and analysis in this area must therefore be a clearly defined set of terms.

Widely used but ill-defined concepts of 'efficiency' lead to misleading conclusions. In part this is because different disciplines (irrigation engineers, economists, agronomists, resource planners) infer 'benefits' that conform to their particular point of view (more precise application of water, higher value of water, higher crop yields, availability of water for alternative uses). Some, all or none of these good things can be the outcome in the multiple scenarios in which 'improvement' takes place.

[1] The common term for increasing the beneficial component of use is an increase in irrigation efficiency - a concept now rejected by ICID precisely because of counter-intuitive results such as this (Perry, 2007 - see Figure 2.1).

Figure 2.1 Modern technologies may induce an increase in water consumed



Source: Hellegers and Perry (2004).

In consequence, the International Commission on Irrigation and Drainage has over the last two years consulted all its National Committees, various Working Groups, and many experts, and adopted terms that avoid the word 'efficiency' altogether, relying instead on the hydrological framework that simply defines component water flows (Perry 2007). These are:

1 *water use*: application of water to any specified purpose, comprising;
2.1 *consumed Fraction*: Water evaporated or transpirated, comprising;
2.1.1 *Beneficial Consumed Fraction*: Water consumed for the desired purpose;
2.1.2 *non-beneficial Consumed Fraction*: Other evaporation or transpiration;
2.2 *non-consumed Fraction:* Water not lost to the atmosphere, Comprising;
2.2.1 *recoverable fraction*: Water that can be recovered and re-used;
2.2.2 *non-recoverable fraction*: Water that cannot be economically recovered;

The benefits of this framework include: identification of consumptive uses (crops transpire water - a consumptive use - while most domestic uses are non-consumptive. Low-flow showers reduce water *use* but have no effect on *consumption*); clarity in identifying how water can most effectively be saved (by reducing *non-beneficial* consumption and the *non-recoverable* fraction); and making sure that the accounts are done properly, because the sum of the component flows at each level MUST add up to the flow at next level.

Traditionally, 'irrigation efficiency' has been calculated as the ratio of 2.1.1, above, to 1 - a term that can vary greatly depending on the scale of observation.[1]

The term 'Water Use Efficiency' is also proposed by ICID to be replaced by 'water productivity'. Although WUE is internationally defined as a productivity term (output of crop per unit water applied, for example), it is one of the most misused terms in the literature.

Other terms needed for the analysis are evaporation (E) which is direct consumption of water - for example when wet soil is exposed to the atmosphere - and transpiration (T) which is the water that goes through the crop in the process of plant to growth.[2]

Improved irrigation technologies (drip, sprinkler) basically change the relative size of the *fractions*. Typically, the *beneficial consumption* fraction increases (from perhaps 40% to 70%), but the other components (before and after improvement) depend on local conditions. If the water table is saline, infiltration is lost to further productive use; if the water table is extremely deep, infiltration may remain 'stranded' in the unsaturated zone, et cetera.

The first implication of this approach is that the analytical framework for assessing the impact of improved technology must take account of local hydrogeological conditions. The simple ratio of water consumed by the crop to water applied is of no particular use in assessing the impacts of improved technology from a resource perspective. Until the destination of the *non-consumed* fraction is known, water savings are indeterminate.

From the farmer's perspective, however, the situation is rather clearer: improved technologies result in a higher level of beneficial consumption - which is the fraction that actually produces crops and income for the farmer. So from the farmer's perspective every unit of water *used* - whether pumped from the aquifer or diverted from a canal - is more productive because a higher proportion goes to beneficial consumption.

[1] Egypt is 85% 'efficient' at the national scale, but only about 40% efficient at field scale, because most field 'losses' simply return to the Nile. Because of this measured diversions from the Nile are at least 50% higher than the water available to the country - a rather confusing statistic that suggests that a further reduction in 'efficiency' could make even more water available to Egypt!

[2] ET is the combined total of evapo-transpiration which is measured - for example in lysimeter experiments. It is often difficult to precisely separate ET into its constituent components based on field measurements.

This, in turn increases the value of water use: if the farmer could afford to pump from 100m when the beneficial fraction of the water pumped was 40%, he can afford to pump from much deeper when the beneficial fraction is 80%.

Therefore, while the intervention described in the first section of the literature review act to decrease the attractiveness of water use as a means to discourage demand, improvements in technology have the reverse effect and actually increase demand.

Consequently, starting from a situation where groundwater use is excessive and difficult to control, improved technology will generally make the incentives to over-exploit the resource even higher, and the difficulties of control similarly more severe.

3 Policy Analysis

3.1 Background

Though it is not the purpose of this study to add to technical information regarding the status of aquifers, some estimates are summarised. It shows that different estimates are available. Although it is not clear which ones are most accurate, estimates point in the same direction.

The annual renewable water resources of the Republic of Yemen are estimated at 2.5 billion cubic meters (BCM), while the current population is 21.6 million people. Currently, per capita availability of water in Yemen is therefore less than 120m^3 a year compared to an average of 7,500m^3 per capita for the world and 1,250m^3 for the Middle East and North Africa. The minimum required for food self sufficiency is 1,100m^3 per capita per annum.

Water scarcity is more acute in the western part of the country where 90% of the population is concentrated. Major cities are located there, in catchments with limited local water resources. Examples of such water-stressed catchments are the Upper Wadi Rasyan and the Sana'a Basin that include, respectively, the city of Ta'iz and Sana'a.

Average rainfall is annually approximately 60BCM; most of it evaporates in situ shortly after rainstorms. The remainder goes as surface runoff or percolates into the ground to recharge to local aquifers. The average yearly runoff used as surface water in the Wadis is estimated to be about 1.0BCM. The percolated amount is estimated to be 1.5BCM, which is going to renew the groundwater. Hence, total annual renewable water resources are 2.5BCM, while annual abstraction is 3.4BCM. This means that *0.9BCM* of groundwater is depleted every year, which lowers the water tables in some aquifers by as much as 6 meters per year (JICA, 2007). Redecker (2007) reports annual abstractions of 4.45BCM in 2006 of which 3.981BCM for agriculture and 0.465BCM for domestic consumption. This gives an annual deficit of *1.95BCM*. This figure is based on gross abstraction and does not allow for recharge from pumped water. Al-Hamdi (2000) estimated that in 1994 total water use in Yemen was 2.8BCM and total renewable water 2.1BCM, leading to an annual deficit of *0.7BCM* in 1994.

The amount of water used in agriculture is currently about 88% followed by urban 10% and industrial use 2%. This is expected to change by 2025 to respectively 79, 18 and 3%.

The imbalance between recharge and abstraction varies among basins and sub-basins. The water balance in the Sana'a Basin, where the capital of Yemen is situated, illustrates the very severe imbalance in some of the basins very well. Table 3.1 shows that the abstracted amount is more than five times the recharge amount (JICA, 2007). The deficit of about 220MCM annually is being satisfied from fossil groundwater storage. Total fossil storage was estimated to be in the order of 3,220MCM in the Sana'a Basin (Al-Hamdi, 2000). Given a constant abstraction rate, this suggests that storage would be depleted within 15 years[1] (from 2000), or potentially even earlier as groundwater abstractions are increasing.

Table 3.1 **Water Balance (2005) in Yemen and in Sana'a governorate, Taiz and Hadramout governorate (MCM)**

	Domestic abstraction	Irrigation abstraction a)	Industry abstraction	Total abstraction	Total Recharge	Water Balance
Yemen	265	3,235	65	3,565	2,500	-1,065
Sana'a	55.4	209.2	4.8	269.7	50.7	-219
Ta'iz	18.5	39.3	4.2	62	20	-42
Hadramout	40	360	0	400	150	-250

a) Sana'a Actual evapotranspiration is 83.7MCM/year, but calculated abstractions 209.2MCM assuming an irrigation efficiency of 40%.
Source: JICA (2007).

GW-MATE (2008) shows different estimates of the ratio between recharge and current abstraction. For Taiz, this is estimated at 50%, for Hadhramout 13%, and for Dhamar 7%. It becomes clear that the data on water availability are particularly uncertain. Annual rainfall varies from year to year, so that 'renewable' sources are not easily characterised as averages. The deep aquifers are complex and difficult to assess with accuracy; recharge is often lateral, via water-bearing strata that bring water from distant points of recharge; some water is fossil, and is not recharging at all; local 'perched' aquifers intercept verti-

[1] This figure is purely indicative of the scale of excess abstractions - in fact as local resources are depleted the number of functioning wells will fall, and the rate of depletion will decline.

cal infiltration; and there are areas where shallow aquifer overlies the impermeable strata that confine the deep aquifers.

What is certain is that the current levels of gross abstraction in many areas is much higher than recharge from all sources, so that water levels are falling, and most aquifers are expected to fall. The most acute problems regarding overdraft are found in the highland plains of Yemen extending from Sadah to Taiz where most of the population of Yemen live and work. Groundwater levels are declining at alarming rates and they are expected to continue declining unless some actions are taken. The socio-economic results of depletion will be dramatic. Already Yemen is witnessing a decline in the areas cultivated by irrigation from wells.

In this chapter the major government policy decisions which have affected the incentive structure facing farmers will be described. A distinction is made between developments in the agricultural sector and in the water sector as well as macro-economic developments. The policy analysis is partly based on discussion with government officials, among others His Excellency the president of Yemen. See appendix 1 for a summary of some of these discussions and a list of the officials met. The physical development of water resources since 1970 can best be illustrated and understood on the basis of the development of the cropped area over time by source of water.

3.2 Categorisation of farming systems according to the source of water

Most of Yemen has an arid climate. Rainfall is erratic and limited while the agricultural demand for water is high - as much as ten times the average rainfall. Rainfed agricultural production depends on capturing and retaining as much rainfall as possible, and selection of crops that are tolerant of water stress. The resulting levels of productivity are rather low - as in most areas with similar conditions. Irrigated agriculture provides the basis for far higher levels of productivity, and over the centuries, several distinct methods of irrigation have evolved.

Spate irrigation involves construction of dams across riverbeds, and associated distribution systems to carry floodwaters to nearby fields. The dams were often temporary structures constructed in series on ephemeral rivers or wadis, and did not survive major floods. Spate irrigation, while more productive than rainfed agriculture, still depends on unpredictable rainfall events to provide erratic irrigation.

Spring irrigation depends on the flows from naturally occurring areas where the groundwater from surrounding hills reaches the surface. Man-made springs (where a gently sloping tunnel is constructed so as to intersect the water-table and induce flow to a specific point) are also common in Yemen, as elsewhere in the region. The flow of water from springs is usually at a low rate, but relatively continuous (the opposite of spate irrigation - although in both cases the water supply is uncontrolled) and consequently provides a more assured agricultural environment.

Well irrigation from shallow aquifers also developed, providing a controlled source of water based on pumping. This was by far the most assured source of water, at least in the short term/seasonal sense. In the longer term shallow aquifers tended to become over-exploited as the number of wells increased, the population increased, and the demand for water for domestic and agricultural products increased.

Importantly, though, these three traditional sources of water for agriculture were self-regulating. Each is dependent on current or recent rainfall, or on the rainfall in recent years. Therefore, while the country was very water-short, an approximate annual balance between renewable supply and utilisation was unavoidable. In this context farmers had extensive experience of the likely levels of water availability, and traditional, negotiated systems of rules and organisation evolved for the development and management of the water resource. Disputes arose, because water was extremely scarce, but the transparency of the link between availability, location and use allowed local reconciliation procedures and judgment to guide the process towards agreements and rules. Lichtentaeler reports in detail on the essential linkage between land ownership and water rights, and the negotiations required when land use changed so as to affect the runoff to established downstream riparians; Ward reports the many ways in which priorities are defined.

According to Agricultural Statistics (MAI, 2001) the total agricultural land is 1.66 million ha, of which the cultivated land varies from 0.98 million ha to 1.5 million ha according to the amount of annual rainfall. Common categorisation of farming systems in Yemen is done according to the source of water. Four systems categories are identified: rainfed, well irrigated (groundwater), spring irrigated (perennial) and spate irrigated (flood). The data in table 3.2 indicate that the cultivated area under well irrigation increased from 2% in 1975 to 40% in 2000, while the cultivated area under rainfall decreased from 85% to 45% in the same period.

Table 3.2	Development of cultivated areas (x 1,000 ha) in Yemen according to the source of irrigation between 1975 and 2005				
Year	**Rainfed**	**Well**	**Spring**	**Spate**	**Cropped area**
1975	1,285	37	73	120	1,515
1990	685	310	25	101	1,121
1995	579	368	20	100	1,067
2000	515	457	46	126	1,144
2005	609	393	34	137	1,202

The cultivated area of Yemen was estimated in 2005 to be about 1.2 million ha of which 50% is depending on rainfall (608,525ha) , while 50% (593,588ha) is irrigated either by groundwater (393,089 ha.) or surface water from seasonal floods (spate irrigation and irrigation by springs). These percentages vary among basins. In Wadi Hadramout less than 10% of the cultivated area depends on rainfall, while 90% is irrigated (see table 3.3). In all three basins around 35%-40% of the cultivated area is under well irrigation.

Table 3.3	Cultivated areas (x 1,000 ha) according to the source of irrigation in 2005 in Sana'a, Taiz and Hadramout governorate					
Year	**Rainfed**	**Well**	**Spring**	**Spate**	**Other a)**	**Cropped area**
Sana'a	66.5	53.2	3.5	1.5	8.3	133
Taiz	41.9	26.1	2.6	0.5	1.9	73
Hadramout	(8)3.7	(12)13.4	6.7	14.2	0	(20)38

a) Others includes tankers.
Source: Agricultural Statistics Book, 2005 (Ministry of Agriculture and Irrigation, 2006).

The increase in cultivated area under well irrigation can be explained on the basis of the development of the cropping pattern shown in table 3.4.

Table 3.4	Development of cropping pattern (x 1,000 ha) between 1990 and 2005						
	Yemen 1990	**Yemen 1995**	**Yemen 2000**	**Yemen 2005**	**Sana'a 2005**	**Taiz 2005**	**Hadhra 2005**
Sorghum and Millet	643	540	463	530	27.1	38.0	(0)12.0
Maize	52	43	32	39	5.0	5.0	0.1
Wheat	98	102	87	86	20.0	0.2	(2.2)4.0
Barley	52	50	37	35	13.0	0.1	0.0
Total Cereals	*845*	*733*	*619*	*689*	*65.1*	*43.3*	*16.1*
Tomatoes	11	13	17	15	2.0	0.4	0.3
Potatoes	14	14	17	17	1.4	0.2	0.2
Other vegetables	27	27	31	42	3.3	8.7	2.9
Total Vegetables	*52*	*54*	*65*	*74*	*6.7*	*9.3*	*3.3*
Sesame	19	23	32	19	0.0	0.2	0.7
Cotton	10	13	27	18	0.0	0.0	0.0
Tobacco	4	4	5	8	0.0	0.0	0.4
Coffee	25	27	33	29	9.0	0.0	0.0
Total Cash crops	*58*	*67*	*97*	*73*	*9.0*	*0.2*	*1.1*
Grapes	17	21	23	12	10.0	0.1	0.0
Palm Trees	15	19	23	14	0.0	1.0	5.0
Other fruits	24	35	46	57	6.8	1.4	1.6
Total Fruits	*56*	*75*	*92*	*83*	*16.8*	*2.5*	*6.6*
Alfalfa	17	21	26	21	2.0	0.0	3.0
Sorghum fodder	44	63	90	102	3.3	6.6	6.4
Total Fodder	*61*	*84*	*116*	*123*	*5.3*	*6.6*	*9.4*
Total Pulses	*49*	*54*	*52*	*39*	*7.2*	*0.6*	*0.0*
Qat	*80*	*90*	*103*	*124*	*23.0*	*10.0*	*0.0*
Total area	*1,201*	*1,157*	*1,144*	*1,204*	*133*	*73*	*37*

The area used to grow vegetables, fruits and qat, which are mostly grown under well irrigation, has increased; the area rainfed cereals has decreased substantially. The area under qat was only 8,000ha in 1970 and 70,000ha in 1980, while it is now more than 125,000 ha. In Yemen 10% of the cultivated area is under qat in 2005. In Sana'a and Ta'iz even larger percentages of the cultivated areas are under qat (respectively 17 and 14%), while in Hadramout hardly any qat is cultivated. The area under fruit and vegetables was 39,000ha in 1970 and 75,000ha in 1980, while it is now more than 150,000 ha. The area under cereals decreased from 1,080,000ha in 1970 to 850,000ha in 1990. The overall cultivated area remains rather stable with some annual fluctuations.

The number of wells in Yemen rose from a few thousand in 1971 to more than 50 thousand at present. Some believe that the number of wells may be in the order of 60 to 70 thousand. In the Sana'a Basin it is estimated there are more than 12 thousand wells. The 200 to 300 rigs available in Yemen are not sitting idle. Wells are still drilled without permits from NWRA even after the passing of the Water Act in 2002. Despite the fact that there is no reduction in the number of wells drilled every year, the cropped areas in some of the governorates is decreasing as a result of the decrease in irrigation water extraction per well (because of the lowering of the water table).

Crop yields have declined or at best remained static over time, despite the increasing availability of labour to work on decreasing areas of land and despite increasing mechanisation and use of fertilisers and pesticides.

So the increase in well irrigation is not the result of the increase in the size of the cultivated area-which remains rather stable over time - nor the result of higher crop yields, but can mainly be ascribed to a shift in the composition of the cropping pattern (towards irrigated crop). Focus will therefore be on the irrigated water-intensive crops and their irrigation water use per hectare.

The shift from rainfed and runoff-fed agriculture to groundwater based irrigation was partly financed by remittances earned by up to one million Yemenis working in Saudi Arabia and the Gulf from the mid seventies up to the Gulf War in 1990. The main drivers of the water crisis in Yemen since 1970 are described in more detail below.

3.3 Physical development of water resources since 1970

The three traditional sources of water for agriculture were self-regulating. As already noted, this changed dramatically in the 1970s with the arrival of tubewell technology. The new pumping technology allowed exploitation of the rechargeable 'shallow' aquifer that is recharged annually by rainfall to much greater depths, and at higher rates. Recharge and net abstraction quickly became unequal and water tables fell. More advanced well construction allowed exploitation of water from deep aquifers whose recharge characteristics are much more complex than the shallow aquifers, and indeed whose water content often comprises infiltration from many years previously.

Exploitation of this resource is not 'naturally' regulated by the annual rainfall, and carries with it the danger of unsustainable use. Dependency on this resource (which is now the dominant situation in many areas) has socio-economic implications for society as a whole and most directly for those whose livelihoods are based on agriculture.

In the subsequent period, Yemen - already one of only four countries in the world designated as absolutely water short, with per capita annual availability of 120 cubic meters compared to an average of 7,500 cubic meters per capita for the world and 1,250 cubic meters for the Middle East and North Africa - saw irrigation from wells expanded tenfold - from 40,000ha to over 400,000ha. There are about 50,000 private wells in the country (8,000 operational wells in the Sana'a Basin alone, half of which are tubewells), together with more than 200 drilling rigs.

Groundwater use began to exceed recharge in the mid 1980s, with more than 80% of abstraction going to irrigated agriculture. At the present rate of depletion, the sustainability of livelihoods is jeopardised. Already, farming has been scaled down or abandoned, and some communities and towns are also running out of domestic water.

See appendix 2 for a detailed description of factors that have triggered groundwater overdraft.

Agricultural development

Currently there are no formal trade barriers on crops. In 1984 the Government of Yemen but a ban on fruit imports, which encouraged farmers to change their cropping patterns in favor of fruits that depended on irrigation from wells. This ban was removed in 1995 during trade liberalisation negotiations in order to fulfil requirements for entering the WTO. In parallel with this general shift towards more productive, groundwater-based agriculture, many migrant workers returned to Yemen after the first Gulf War with money to invest - and opted for irrigated agriculture.

And most importantly, qat production, trade, and consumption became a very substantial part of the economy. Qat is an extraordinary crop. Once established, it is drought tolerant, requires only well-drained, usually poor quality soil, and produces the new shoots that are harvested and marketed throughout Yemen more or less 'on demand' in response to one or two heavy irrigations. Consequently, farmers can time their production to meet the demand peaks that coincide with major festivals, or simply to respond to expected favorable market conditions.

The market is well developed and efficient, with various arrangements between the farmers and the traders. Qat can be harvested in small or large quantities according to the farmer's need for money, and it brings cash in on the very day of harvest. From the economic viewpoint qat creates a regular and large transfer of money from town to country. It pays high returns to water, but is the major user of the nation's rapidly depleting groundwater.

Output prices of qat are high compared to the import price of qat from countries like Ethiopia. Officially qat imports are allowed, but in reality it does not happen - the single attempt to do this ended unsuccessfully. Domestic producers hinder such imports in order to keep the price of qat at a high level. This means that there exist informal obstacles for qat import. It is important to note in this respect that this is not a formal policy. Formally qat is taxed. However, the Government of Yemen only collects a small part of the tax and is not trying hard to remove the import obstacles as it will affect their trade balance and the income of rural qat producers substantially. Besides historically donors did not like such imports.

This shows that past attempts at regulation proved ineffectual. Even if formal regulations are in place, they are often not enforced at the central level since at the local level customary laws are enforced. Informal groundwater markets - which require that water rights are in place and enforced - consequently only exist at the local level.

Qat has become a very large part of the economy - some estimate as much as 25% of GDP, 16% of employment and 30% of water use.[1] The government has had no explicit policy on the stimulant qat, and implicit policies are ambiguous; development programmes exclude it, yet qat is a prominent part of public life.

In sum, developments after 1970 constituted a powerful engine pushing in the direction of depleting Yemen aquifers by subsidising inputs and protecting outputs, consequently making irrigation highly profitable with little control from law and tradition. Qat, meanwhile, was once a weekend habit of the well-off, but has now become part of the Yemeni way of life.

Policy development in the water sector

Since 1975, the government, through different ministries, regional development authorities, and the cooperative and Agricultural Credit Bank supported a major investment programme to expand the cultivated area under well irrigation.

[1] Reported in Ward, C., Building Block - Qat, 1999. (World Bank working paper).

The public and private sectors have drilled thousands of wells and equipped them with pumps and motors to extract underground water resources for the expanding agricultural economy especially the production of fruits, vegetables and most importantly qat.

In addition to the direct investments by the government in irrigated agriculture, subsidies were provided to the private sector to import pumps, motors and rigs. The Cooperative and Agricultural Credit Bank provided loans at subsidised rates for irrigation. Diesel and electricity prices were kept very low compared to international prices. Consequently, virtually all aspects of groundwater development and exploitation have been supported and subsidised by government actions over the last 30 years.

Since the mid-1990s the government of Yemen has been aware of the water crisis and has begun taking steps to mitigate the water problem. Pressure and encouragement from the World Bank, UNDP and the government of the Netherlands resulted in noticeable changes in policies of the government concerning the water sector. One of the most important developments in the water sector was the creation in 1996 of the National Water Resources Authority (NWRA) with responsibility for water resources planning and monitoring, legislation, regulation and public awareness. In the year 2003, the Ministry of Water and Environment was established to oversee the water and environment sector and in 2005 the National Water Sector Strategy and Investment Program for the period 2005 to 2009 was prepared for implementation (NWSSIP 2005-2009).

This document is of fundamental importance in defining the policy position of the Government with respect to water resources management and development. Key statements of the NWSSIP of relevance to the aims of this study are set out in appendix 3 In brief, the strategy emphasises:

- ensuring the maximum possible degree of sustainability;
- allocative efficiency, subject to priority for domestic uses;
- demand management, including economic incentives;
- regulatory measures (including community self-regulation);
- assignment of water rights linked to specific uses.

The NWSSIP document is direct in its reference to the role of qat (pages 10-11):

> *Qat now occupies at least half of the irrigated area in Yemen, growing at an annual rate of 9% (double the growth rate of other crops). This crop has even invaded virgin land never cultivated before, in addition to expansion in regions not known for its cultivation.*

The reality is that between 1970 and 2000 the area under other crops, particularly grapes and coffee, has also expanded annually at nearly 3 and 5%, respectively. However, the area under qat expanded at a much faster rate (9% per year) because it is more profitable.

If the existing situation continues as it is, without intervention, then qat farming will in the end deplete the water in the rural areas and consequently wipe out the rural economy… serious consideration should be given to allowing qat importation.

Indeed, the hard-currency spent on developing qat farms in neighbouring water-rich countries, which would permit qat growing and export to Yemen, will be much less than the hard-currency which Yemen currently spends on qat irrigation (subsidised diesel fuel; maintenance and depreciation of drilling rigs; cost of well casings, pumps and spare parts; well deepening and drilling) as well as the cost of pesticides for spraying qat shrubs and the cost of the medical bill for treatment of the pesticides-caused diseases (as Qat shrubs growing in a humid environment like Ethiopia will not need an intensive use of pesticides). This is in addition to the value of the water which will be saved as a result of reducing qat farming in Yemen.

These extracts from the NWSSIP document - not least the final paragraph - are a clear recognition of the scale of the problems facing Yemen, and a well articulated list of the issues to be addressed in resolving the over-exploitation of non-renewable resources. Implementation remains the challenge, and this report identifies some of the limitations that will be found in trying to implement demand management approaches through the use of economic instruments.

Macro-economic context

The recent (November 2006) Development Policy Review highlights and reinforces many of the problems faced in the water sector, but does not provide an optimistic backdrop to the difficult challenges faced. Key points are that in order to redress fiscal imbalances, tax revenue must rise and public expenditure fall. (The report anticipated full removal of the oil subsidy, which then accounted for some 8% of GDP, by 2007).

Yemen's balance of payments is strongly linked to oil. The country is an oil producer and exporter and also an importer of refined products. Oil is a major source of revenue to the government, but subsidies on oil products are a major government expenditure and are assessed as being poorly targeted, with only 25% reaching needy groups.

The DPR bases its projections on assumptions that oil is expected to remain above USD55/barrel until 2001[sic - the accompanying graph in the DPR suggests that 2011 is intended], after which a steady decline is expected and then a stabilisation between USD35-40 for the long term. While Yemeni oil production is expected to fall in the medium term, Yemen already imports more than half of its diesel (the main fuel used in irrigation), and sells it at 39% of the world price. These figures relate to 2005, when oil prices were around USD60 per barrel. With prices now in excess of USD100 per barrel, the sensitivity of Yemen's economic future (and the costs to government of subsidies) is clear. It is likely that domestic oil pricing policy decisions will be strongly influenced by a number of factors beyond their impact on the demand for water. While internal pressures for fiscal stability and external pressures from donors will continue in the direction of higher domestic oil prices. The recent rise in oil prices simultaneously reduces overall fiscal pressure by increasing revenues while requiring strong government action to avoid an offsetting increase in the level of subsidies required to maintain current domestic prices.

This scenario strengthens the case for improved irrigation technology to the extent that this is an energy saving measure, *provided* demand for water does not expand.

The DPR notes that the civil service is weak, and that corruption is a serious problem. The enforcement of regulations such as those required to control over-abstraction of groundwater will be particularly challenging in these circumstances. Of the five key elements set out in the DPR (maintaining fiscal sustainability, improving the investment climate, managing energy resources, managing water resources, and slowing population growth) groundwater irrigation constitutes one and is closely linked to two others.

The assessment of the DPR in respect of water use in its broader economic context is clear and to the point: conserving groundwater, sustaining the rural economy, transferring water to higher value uses, and addressing poverty are sound objectives that are difficult to reconcile. Progress on any one element is likely to threaten at least one of the others.

The technical prescriptions set out in the DPR are less well articulated. Increasing the efficiency of irrigation and water markets are proposed, with 'development of formal water markets a priority'. The former will be addressed separately where the implications of taxes and subsidies are considered. The issue of water markets is addressed below.

Water markets are often seen as a means of transferring water from lower to higher value uses (whether from agriculture to industry, or from a less productive to a more productive farmer). Water markets are often confused with markets in pumping services - where well-owners who pump from the same aquifer sell water to local farmers. In this case, the 'market' is not for water but rather for the use of the pump and well.

Many well owners sell water to neighbours, and water is routinely trucked from wells to distant fields and to cities (major cities such as Sana'a depend primarily on water tankers for domestic supplies). The water market is in fact already in operation - and the value of water is already determining its allocation and is driving the unsustainable pumping of water.

Establishing water rights at levels below those which well-owners would wish to pump is an exceptionally difficult task in any circumstances. The Ogallala aquifer that underlies vast areas of America's farmland is over-exploited in many areas, but attempts to control pumping have failed. In India, where the writ of government is relatively strong in rural areas, water rights for groundwater are undefined (the landowner 'owns' 'all' the water beneath his land) and agricultural production in large areas - for example in the western state of Gujarat - has collapsed, or is threatened by reduced supplies or reduced quality. In the North China Plain, groundwater levels have been falling for many years and only recently have there been local successes in persuading farmers to limit their irrigation to sustainable levels.

In Yemen the challenge of establishing water rights at sustainable levels is compounded by the weakness of government in rural areas, where tribal rules and powers are far more important than edicts from the centre.
Hence, the primary issue is not tradability of rights but establishing water rights in the first place, and establishing these rights at levels that make significant contributions to the sustainability of water use. According to the recent JICA study of the Sana'a Basin, this would mean *inter alia* a 70% reduction in the irrigated area. Whether water rights are tradable or not in such a context is a second order issue compared to the definition (at individual well level) and enforcement of the right to pump.

Summary of the present situation in Yemen
Aquifers are being overexploited at rates that are already forcing farmers to abandon wells; cities are serviced largely by water tankers; government policies that originally drove this over-development (subsidies on wells; controlled imports; cheap diesel) are still at least partially in place. Meanwhile government has a comprehensive policy in place but limited power to undertake the ex-

tremely difficult tasks that are required - most significantly the establishment and enforcement of water rights that will allow sustainability to be achieved and water to be diverted from existing uses to the priority uses defined in policy.

Current donor interventions therefore centre on the less challenging goal of introducing new technologies that are designed to 'save' water. In parallel with these investments, farmers are encouraged to join together to address their problems collectively. In the Yemeni context the latter makes sense; group pressures in rural areas are stronger than the government. The water policy supports this, and also stresses the need for information, so that farmers can make informed (if still exceptionally difficult) choices about how they utilise their resources. Some are reported to be doing this, and are for example banning the construction of new wells, deepening of existing wells, and export of water.

This report evaluates in chapter 5 an additional tool that is part of government's expressed policy-economic instruments that influence the demand for water.

4 Empirical Field Work

4.1 Approach

To get a better understanding of farmers behaviour regarding groundwater extraction in-depth interviews with about one hundred farmers have been executed in each of the study areas: the Sana'a Basin, the Upper Wadi Rasyan (Taiz) and Wadi Hadramout (excluding coastal areas).

First of all the three study areas have been visited, which helped the consultants to better understand some of the issues facing farmers in the region.

Secondly, questions for the survey have been prepared in close collaboration with NWRA. The steering committee has reviewed the questionnaires. Afterwards the questionnaire was field-tested. It turned out to be too long and too detailed. On the basis of that it was modified and submitted to NWRA again for approval. See the final version of the field survey questionnaire in appendix 4. It includes general questions, questions regarding financial incentives faced (subsidies), non-financial incentives of farmers behaviour (household livelihoods objectives, traditional rules and customs regarding water, community solidarity), role of the institutional and regulatory structure in modifying farmer behaviour, farmer and community wisdom and mobilisation capacity. After approval it was translated into Arabic.

The field work in each of the three basins started with training the NWRA and MAI enumerators, who undertook the surveys. NWRA entered the data into SPSS for the analysis. The project team has provided overall monitoring of the field work and analysed the results.

The NWRA field team coordinators played an active role in the selection of the sample. In total 27 districts in 3 governorates were visited to interview 385 farmers, see table 4.1.

The empirical field work at the farmer level is carried out over a two months period (March and April 2008). About 133 questionnaires (including some pretests and surveys to train the enumerators) were executed in the Taiz Basin in the period between 2-11 March 2008. About 115 surveys were executed in Wadi Hadramout in the period between 22-30 March 2008 and about 137 surveys in the Sana'a Basin in the period between 7-16 April 2008.

Table 4.1	Number of farms interviewed in each district	
Sana'a Basin	**Taiz Basin**	**Wadi Hadramout**
17 in Bani-Alharith	10 in Saber Al-Mawdem	5 in Al-Soom
28 in Sanhan	39 in Taiziah	17 in Syoon
14 in Khwlan	18 in Dh-Sofal	30 in Triem
30 in Bani-Hashish	15 in Al-Makha	10 in Saah
14 in Nihm	4 in Magbanah	23 in Al-Qatn
16 in Hamdan	9 in Khadyer	9 in Haorah Wadi-Alain
12 in Arhab	6 in Sharab Al-Ronah	21 in Shbam
6 in Bani-Matar	15 in Mawia	
	9 in Al-Mafer	
	2 in Gabel-Habashi	
	5 in Shrab-Alsalam	
137 in Total	*133 in Total*	*115 in Total*

4.2 Results of the field survey

General characteristics

Farmers seem to have a lower education level in Wadi Hadramout (91% of the famers did not go to secondary school) than farmers in the Sana'a and the Taiz Basin (see table 4.2). A smaller number of people depend on the farm in Taiz (at 85% of the farms less than 20 people) than in the Sana'a Basin and Wadi Hadramout. About 33% of the farms in Sana'a have non-agricultural income and 26% of the farms in Taiz, but only 12% of the farms in Wadi Hadramout.

The average farm size in Sana'a is 2.5ha and 7.5ha in Wadi Hadramout, while the average farm size in Taiz is somewhere in between. The size in Taiz depends on whether a few exceptionally big farmers are taken into consideration. The percentage of farms with less than or equal to 1ha in Sana'a, Taiz and Hadramout is respectively 42, 52 and 1%. In Taiz a substantial part of the land (about one-third) is rented.

In Sana'a more than 50% of the farms have more than one well, while this number is significantly lower in Taiz. and in Wadi Hadramout. In Sana'a and Taiz water is more actively traded than in Wadi Hadramout. About 60% of the farmers in Sana'a and Taiz buy water. In Taiz farmers mainly buy from neighbors, while in Sana'a tankers also play a substantial role.

In Hadramout 65% of the farmers get as much water as they need, while only 17-18% of the farmers in Sana'a and Taiz get sufficient. In case of extra water: 55% of the farms in Taiz would sell it and 45% of the farms in Hadramout would leave it in the well (they have already sufficient water). About 14-19% would expand the area and 15-27% would apply more.

The field survey shows evidence that in the Sana'a Basin the distribution of wells is strongly bimodal. There are a lot of relatively shallow wells (about 20% is less than 40m deep) and a lot of deep wells (about 70% is more than 150m deep). About 65% of the wells in Taiz are less than 80m deep, while 90% of the wells in Hadramout is less than 150m deep. The average well depth in Sana'a, Taiz and Hadramout is respectively 254, 107 and 86m, while the average depth of the water table is respectively 180, 94 and 63m. About half of the farms in Sana'a and Taiz have deepened their well over the last 10 years and one-third of the farms in Wadi Hadramout. Farmers' perception of water quality is worst in Wadi Hadramout although still about half of them consider the water to be of a good quality.

Table 4.2 **General characteristics of the farms surveyed in the three study areas**

	Sana'a	Taiz	Hadramout
Illiteracy of farmer (%)	13	20	17
Able to read and write (%)	19	23	28
Primary school and preparatory school (%)	18	14	46
Secondary school (%)	24	23	6
Diploma (%)	2	5	2
Bachelor degree (%)	24	16	1
≤10 people live from the farm (%)	22	38	16
>10 ≤ 20 people live from the farm (%)	48	47	47
>20 ≤ 30 people live from the farm (%)	16	9	20
>30 ≤ 40 people live from the farm (%)	5	3	9
>40 ≤ 50 people live from the farm (%)	6	2	3
>50 people live from the farm (%)	4	2	6
Non-agricultural income: yes (%)	33	26	12
Average farm size (ha)	2.5	5	7.5
Farm size ≤1ha (%)	42	52	1
Farm size >1 ≤ 5ha (%)	46	31	50
Farm size >5 ≤ 10ha (%)	7	7	27

Table 4.2	**General characteristics of the farms surveyed in the three study areas (continue)**		
	Sana'a	**Taiz**	**Hadramout**
Farm size >10 ≤ 20ha (%)	4	3	16
Farm size >20 ≤ 50ha (%)	1	4	7
Farm size >50ha (%)	0	4	0
Yes, rent out (part of) the land (%)	5	29	11
Yes, one well (%)	45	50	93
Yes, more than one well (%)	51	11	7
Yes, selling water (%)	13	41	1
Yes, buying water from neighbor (%)	44	62	1
Yes, buying water from tanker (%)	17	4	0
Yes, getting as much water as needed (%)	18	17	65
With extra water the farmer applies more (%)	27	15	27
With extra water the farmer changes crop (%)	27	0	9
With extra water the farmer expands area (%)	14	15	19
With extra water the farmer sells water (%)	27	*55*	0
Extra water is left in the well (%)	5	15	45
≤40m deep well(%)	17	40	21
>40 ≤ 60m deep well (%)	2	15	15
>60 ≤ 80m deep well (%)	1	10	25
>80 ≤ 150m deep well (%)	6	3	29
>150 ≤ 200m deep well (%)	12	8	4
>200 ≤ 250m deep well (%)	14	7	4
>250 ≤ 300m deep well (%)	19	14	1
>300 ≤ 500m deep well (%)	28	0	0
>500m deep well (%)	2	1	0
Average well depth (m)	254	107	86
Average depth of the water table (m)	*180*	*94*	*63*
Yes deepened well over the last 10 years (%)	48	47	32
By how many meters (m)	101	33	22
Perception of water quality: good (%)	71	67	49
Perception of water quality: medium (%)	14	24	30
Perception of water quality: poor (%)	15	9	21

Financial drivers

The results of the field survey show that hardly any of the farmers is aware of any subsidy received for farm expenditures on pumps, diesel, digging the well, improved on-farm irrigation equipment nor subsidies on the conveyance systems (see table 4.3).

Table 4.3 **Financial drivers of the farms surveyed in the three study areas**

	Sana'a	Taiz	Hadramout
No pumps are not subsidised (%)	98	99	100
No diesel is not subsidised (%)	100	100	97
No digging the well not is subsidised (%)	100	98	97
No subsidy on improved on-farm irrigation equipment (%)	99	100	96
No the conveyance system is not subsidised (%)	100	96	100

Non-financial drivers

Table 4.4 shows that about 80% of the farmers in Taiz and Hadramout grow crops for home consumption (like sorghum) and 68% of the farms in Sana'a.

Table 4.4 **Non-financial drivers of the farms surveyed in the three study areas**

	Sana'a	Taiz	Hadramout
Yes, crops grown for own consumption (%)	68	80	82
Average size of area used for own consumption (ha)	1.2	1.4	2.1
Yes, famers did change the cropping pattern (%)	57	63	37
Crops increased			
of which increase in fodder crops (%)	43	66	65
of which increase in qat (%)	26	12	0
of which increase in wheat (%)	4	0	17
of which increase in other crops (%)	27	22	18
Crops decreased			
of which decrease in grapes (%)	25	0	0
of which decrease in sorghum (%)	19	18	13
of which decrease in tomatoes (%)	7	3	5

Table 4.4	Non-financial drivers of the farms surveyed in the three study areas (continue)		
	Sana'a	Taiz	Hadramout
of which decrease in other crops like onion, potato (%)	49	79	82
New crops intended to grow			
of which wheat	32	3	48
of which tomato	11	7	3
of which mango	0	23	0
of which other crops	57	67	49

The average size of the area used for home consumption varies between 1-2 ha. Especially in Sana'a a substantial share (half) of the farm area is used to grow crops for home consumption. In Sana'a and Taiz the majority of the farmers changed their cropping pattern. They increased the size of the area under fodder crops and to some smaller extent the size of the area under qat. In Hadramout there was mainly an increase in the area under wheat. Farmers decreased the size of the area under sorghum and in Sana'a under grapes. They intend to grow wheat in Sana'a and Hadramout and Mango in Taiz.

Regulatory framework

Table 4.5 shows that respectively 29, 35 and 62% of the farmers in Sana'a, Taiz and Hadramout do not know which institution is responsible for well licences. Only in Taiz about half of the farmers is aware that this is the responsibility of NWRA. Half of the farmers in Sana'a who wanted to dig a well were given a licence, whereas this percentage was substantially less in Taiz. Farmers in Taiz find it more complicated to get a licence to dig a well than farmers in Sana'a or Hadramout. It is interesting to note that this has not triggered the number of illegal drillings in Taiz (it is relatively low compared to Sana'a and Hadramout), maybe due to the fact that about 75% of the farmers would inform the authority about illegal drillings. This implies that there a high social control in Taiz.

Table 4.5	The regulatory structure faced by the farms surveyed in the three study areas		
	Sana'a	**Taiz**	**Hadramout**
Do not know which institution is responsible for well licences (%)	29	35	62
NWRA is responsible to give well licence (%)	7	47	13
MAI is responsible to give well licence (%)	7	4	13
Other institutions (like governorate, police) is responsible (%)	57	14	12
Yes, a licence is given to anyone who want to dig a well (%)	50	3	32
It is easy to get a licence (%)	16	4	26
It is complicated to get a licence (%)	63	74	42
Do not know whether it is easy/complicated (%)	21	23	32
Yes, farmers dug a well without a licence (%)	67	32	50
Yes, farmers informed authorities about illegal drilling (%)	40	76	20

Collective action

In Taiz farmers seem to be more organised in Water User Groups or Water User Associations than in Sana'a and Hadramout (see table 4.6). Farmers who are a member expect support from projects among others for equipment (like pumps, wells, drills), but also to be organised. Farmers decided not to become a member for various reasons: the association is far away, they are too old, they do not like the responsibility, no time, registration has not started yet, it is costly and it is only for a limited number of persons (especially Al-shikes and village leaders). Most farmers in Sana'a and Taiz previously discussed their problems already with others, like neighboring farmers.

Table 4.6	Collective action of the farms surveyed in the three study areas		
	Sana'a	**Taiz**	**Hadramout**
Yes, there is a WUG or WUA in the village (%)	19	37	11
Yes, the famer surveyed is a member (%)	18	35	8
Yes, previously discussed water problems with others (%)	84	91	21

Individual and community wisdom

The results of the field survey show that most farmers (more than 80%) think that the groundwater levels will increase after the rains and that Allah owns the water (see table 4.6). The majority of the farmers interviewed think that god owns the water, although a quarter of the farmers in Sana'a and Taiz think that the water is owned by the well owners. If water is becoming more scarce, about 80% of the farmers think it is better to use less and make it last longer and agree as a group to use less water. Only about 20% propose to use it quickly before it is finished or before others use it. More than 90% of the farmers in all three areas think that scarcity becomes more dangerous in the future, mainly due to an increase in groundwater overdraft for agricultural and domestic purposes and to a smaller extent due to less rainfall.

The best individual action against water scarcity is according to the farmers to reduce the hours of pumping. In Sana'a and Hadramout reducing water-intensive crops is considered as one of the best actions, while in Taiz the majority does not consider a change in the cropping pattern as a valuable action. The majority realises that putting new wells is not a good action.

The various actions that can be taking by the community, like limiting the number of wells, reduce hours of pumping, reduce area irrigated and reduce the water-intensive crops, are considered to be useful by the majority of the farmer. In Taiz the majority of the farmers prefer the community to limit the number of wells and reduce hours of pumping instead of reduce the area irrigated and reduce the water-intensive crops.

Less attractive actions that can be taking by the government are to stop the deepening of wells and to reduce the irrigated area. It is interesting that farmers prefer construction of dams and reservoirs, subsidies on improved irrigation technology and organisation of collective action. They are also very much in favour of providing alternative jobs and punishing illegal drillings.

There is a big difference in the percentage of farmers that want to use improved irrigation technology: only about 30% and Sana'a, 100% in Taiz and 88% in Hadramout.

About half of the farmers in Sana'a and Taiz have received advice on saving water, while only a quarter of the farmers in Hadramout have received such advice. They mainly received advice on wise use of water and on improved irrigation technology.

More than a third of the farmers answered that only God knows whether there will still be water for their son and grandson. In Taiz farmers are most pessimistic (about 40% answered that there will be no water for their son and grandson left).

Many farmers do not see an alternative for the future and fear starvation. About 23% relies on God.

Table 4.7	Individual and community wisdom in the three study areas		
	Sana'a	Taiz	Hadramout
Yes groundwater levels increase after the rains (%)	96	92	83
God owns the water (%)	44	56	91
all people own the water (%)	16	12	1
well owners own the water (%)	25	25	5
others (like land owners, government et cetera) own the water (%)	15	7	3
If water is becoming more scarce, is it better to			
Yes use it quickly before it is finished (%)	17	18	26
Yes use it quickly before others use it (%)	18	20	24
Yes use less and make it last longer (%)	93	89	86
Yes agree as a group to use less water (%)	90	89	85
Yes scarcity becomes more dangerous in the future (%)	98	93	90
due to increased overdraft and less rainfall (%)	39	32	26
due to less rainfall (%)	15	11	19
due to increased water demand for domestic purposes (%)	10	13	16
due to increased water demand for agricultural purposes (%)	13	9	5
due to more wells, cities, dams, irregular prayer, projects (%)	23	35	34
What action can you take as an individual:			
Yes put deeper well (%)	82	79	94
,Yes put new well (%)	25	20	47
Yes change technology (%)	81	72	92
Yes change crop (%)	71	45	74
Yes reduce hours of pumping (%)	88	80	90
Yes reduce area irrigated (%)	83	71	83
Yes reduce the water-intensive crops (%)	90	65	95
What action should be taken by the community:			
Yes limit number of wells (%)	86	79	92

Table 4.7	**Individual and community wisdom in the three study areas (con-tinue)**		
	Sana'a	**Taiz**	**Hadramout**
Yes reduce hours of pumping (%)	88	82	90
Yes reduce area irrigated (%)	84	68	87
Yes reduce the water-intensive crops (%)	89	68	96
What action should be taken by the government:			
Yes stop new well digging (%)	82	80	80
Yes stop deepening of wells (%)	55	36	58
Yes reduce irrigated area (%)	69	45	76
Yes reduce water-intensive crops (%)	78	53	88
Yes construct dams/reservoirs (%)	100	94	97
Yes subsidise improved irrigation technology (%)	99	92	99
Yes provide alternative jobs (%)	85	84	71
Yes organise farmers for collective action (%)	100	76	81
Yes punish illegal drilling (%)	88	80	83
Yes, want to use improved irrigation technology (%)	32	100	88
If no, why not?			
Not suitable for certain crops and land types (%)	43	19	100
Because of the absence of extension and subsidies (%)	21	24	0
Unfamiliar and unknown (%)	0	17	0
Other, like no water, they damage quickly, not profitable (%)	36	40	0
If yes, what will the benefit be for you?			
Water saving (%)	77	19	38
Expansion of agriculture (%)	5	38	19
Reduces the costs of pumping (%)	9	0	18
Other, like saves time (%)	9	43	25
Yes have received advice on saving water (%)	54	52	25
If yes, on wise use of water (%)	49	78	62
If yes, on improved irrigation technology (%)	41	20	24
If yes, on other things like construction of dams, qat cultivation (%)	10	2	14
Yes there will still be water for my (grand)son (%)	24	20	51

Table 4.7	Individual and community wisdom in the three study areas (continue)		
	Sana'a	Taiz	Hadramout
No there will be no water for my (grand)son (%)	29	41	15
Only God knows whether there will be water for my (grand)son (%)	47	39	35
What do you see as an alternative for the future?			
Without solution, there will be well depletion and starvation (%)	19	58	19
God will help us (%)	22	23	23
Water saving, rainfall, dam construction, waste water re-use (%)	22	16	31
Improved irrigation technology (%)	2	1	19
Seawater desalination (%)	14	0	0
Immigration to where water is available (%)	10	0	2
Other, like transport, water saving education (%)	11	2	6

5 Evaluation

5.1 Introduction

In this chapter the potential role of economic incentives to reduce unsustainable water consumption in agriculture is evaluated. Incentives that decrease the profitability of water use (by increasing the costs of water or by decreasing the price of outputs) have been evaluated in Section 5.2 The alternative strategy of subsidising improved irrigation technology has been evaluated in Section 5.3. A broader review of the options can be found in Section 5.4.

The policy context, as set out in the Poverty Impact Assessment comprises three components that 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 largely dependent on the level of agricultural activity, there are obvious tensions between these objectives.

Governments act in many ways to influence behaviour and in reality every action (or inaction) by government will have some direct or indirect impact on the agricultural sector and hence on the demand for water.

Government interventions are of three types (see some examples in table 5.1):

Persuasion:

Provision of information to the population in general or target groups regarding the implications of their actions-and suggestions for change.

Incentives:

Interventions (taxes, subsidies, regulating or deregulating markets) that affect the profitability of particular activities.

Regulation:

Actual restriction of water use through allocation and enforcement of quantitative water rights, restricting pumping capacity or hours, or preventing construction of new wells.

Interventions can be narrowly targeted (a specific location; a specific crop; a technology); regional (a basin or aquifer); or national. Some interventions (for example increasing the price of diesel) can only be implemented nationally.

Table 5.1	**Examples - NOT RECOMMENDATIONS - of interventions**		
	National	**Local**	**Individual**
Persuasion	- Information on crop water consumption (How much water does a family use per day; how much water does a day's qat supply use?) - Water saved by imports	- Water balance data - Aquifer life data - Promote/support WUAs	- Extension - Crop options - Technology options
Incentives	- Increase fuel price - Import Qat to reduce price	- Support for establishing and running WUAs - Establish water markets - Meter water use	- Subsidies for improved technology
Regulation	- Enforce water rights - Buy wells for urban use	- Define sustainable water rights - Restricting construction of new wells	- Restricting pumping capacity or hours

The prospects for success - and risk of failure - of any proposed interventions must be assessed from several perspectives.

First, does the Government have the political *will* to implement the policy? Recent attempts to significantly increase the price of diesel produced a substantial backlash, and eventual retreat from the original proposal. An attempt to import qat some years ago was violently resisted by local interests and has not been repeated.

Second - and closely related to political will - does the government have the *power* to implement the policy without generating local or national unrest? While National policies on groundwater propose licensing of wells and prohibition of well drilling and deepening without licences, it is commonly agreed that development continues and enforcement is weak. In the socio-political context of Yemen, where local leaders have more authority than central government on many issues, policies that are not endorsed and accepted at the local level have limited likelihood of success.

Third, all interventions - especially those that are broadly targeted - carry a risk of *unintended consequences*: an increase in the price of diesel will increase the cost of domestic water supply BOTH because water will cost more to pump, AND because transport and distribution costs are a significant proportion of the cost of tanker supplies. It will make some crops (perhaps those most important to the poor) non-viable. Similarly, a decrease in the price of qat may induce increased consumption by urban consumers - with consequent negative health and social impacts - while decreasing rural incomes to qat growers.

5.2 Water saving through instruments that decrease the profitability of irrigation

Whether instruments that decrease the profitability of water use (by increasing the costs of water itself or the costs of other inputs or by decreasing the price of outputs) will reduce significantly the demand for water, requires insight into the crop budgets of the main irrigated crops and the components of those budgets that can be influenced by government interventions. Attention will therefore first be paid to the main irrigated crops.

5.2.1 The main irrigated crops in the study areas

It is important to note in this respect that the data on cropping patterns of irrigated crops may not be reliable because (a) well irrigation is dispersed widely and difficult to account for; and (b) unlicenced well development is known to be happening and it is unlikely that irrigation under these wells is properly reported. Besides data on irrigation water use may also not be reliable, because there is a lot of confusion between 'water applied' to crops and 'water consumption' by crops. For instance in the JICA report (2007) estimated water consumption in the Sana'a Basin of 83.7 MCM is multiplied by 2.5 to get estimated water abstractions of 209.2 MCM, i.e. water applied). The actual irrigation water use figures presented in table 5.2, 5.3 and 5.4 is water applied. As part of actual irrigation water applied returns to the aquifer, it may exceed total net abstraction figures shown in table 2.

The objective of this study is, however, not to assess water balances, but rather to assess the impact of 'economic instruments' on the demand for water. In that case, it is much more important to understand the link between the economic instrument and water demand at the individual crop level than to understand the overall water balance.

Despite these uncertainties there seem to be significant big differences in the actual irrigation water use of the various crops. Some crops use more than 10,000m^3 per hectare, such as alfalfa, fruits and qat. Grapes use about 8,500m^3 per hectare, while most cereals use less than 7,500m^3 per hectare. The average irrigation water consumption per hectare in irrigated agriculture is 9,215m^3 per hectare according to Redecker (2007), given that agricultural irrigation water consumption in Yemen is 3.981BCM and an irrigated area of 432,000 ha. About 81% of qat areas use groundwater, which is more than 100,000 ha. This means that qat occupies about 25% of irrigated land and about 37% of the groundwater used goes to qat.

Table 5.2 **Irrigated area and actual irrigation water use (IWR) in the Sana'a Basin in 2005**

Irrigated crop	Irrigated area (ha)	Actual irrigation water use (m^3/ha)	Total irrigation water use (MCM)	Share in total (%)
Qat	14,997	8,900-12,500	187.5	59
Grapes	7,301	8,400-8,500	62.1	19
Alfalfa	1,402	14,500	20.3	6
Tomatoes	1,953	5,000-5,750	11.2	4
Coffee	2,510	5,000	12.6	4
Wheat, Maize, Barley	1,320	6,220-7,530	8.7	3
Potatoes	1,398	5,420	7.6	2
Sorghum	726	7,401	5.4	2
Onion	646	7,500	4.8	2
	32,253 a)	9,921 b)	320	100

a) The irrigated area in table 5.2 is smaller than the irrigated area in table 3.3, because table 5.2 shows figures for the main irrigated crops in the Sana'a Basin instead of figures for all irrigated crops in Sana'a governorate; b) Total actual irrigation water use in table 5.2 is higher than the figure in table 3.1, because table 5.2 is based on gross abstraction and does not allow for recharge while table 3.1 shows net abstraction.

According to the Sana'a Basin water management project 8,900m^3 per hectare is used to irrigate Qat. This is large relative to the estimated typical per capital water consumption for domestic water usage (about 100 litres per day, which is 36.5m^3 annually). This means that the amount of water used on one hectare of Qat is, equivalent to the consumption of 240 persons. The questions is raised: when water is scarce, who should get priority?

Table 5.2 shows that in the Sana'a Basin about 60% of actual irrigation water use is applied for qat production and about 20% for grapes production. Average water use is about 10,000m^3 per hectare.

Table 5.3 shows that in Taiz more than 35% of actual irrigation water use is applied to qat and about 25% to onion production and 18% to sorghum. Average water use is about 8,000m^3 per hectare.

Table 5.3	**Irrigated area and actual irrigation water use in the Taiz Basin in 2005**			
Irrigated crop	**Irrigated area (ha)**	**Actual irrigation water use (m^3/ha)**	**Total irrigation water use (MCM)**	**Share in total (%)**
Qat	6,435	9,980	64.2	*35.4*
Onion	7,183	6,100	43.8	*24.2*
Sorghum food	4,888	6,700	32.7	*18.1*
Mango	867	18,800	16.3	9.0
Sorghum fodder	2,138	6,700	14.3	7.9
Bananas	375	16,800	6.3	3.5
Tomatoes	364	6,700	2.4	1.3
Potatoes	183	5,600	1	0.6
Total	22,433 a)	8,080 b)	181.2	100.0

a) The irrigated area in table 5.3 is smaller than in table 3.3, because we focus only on Upper Wadi Rasyan; b) The difference in total actual irrigation water use in table 5.3 and table 3.1 can be explained on the basis of the large recharge flows, which are deducted in table 3.1 (showing net abstractions), but included in Table 5.3.

Table 5.4 shows that in Wadi Hadramout more than 40% of actual irrigation water used is applied to alfalfa and about 24% to wheat production. Average water use is 7,500m^3 per hectare.

Table 5.4	Irrigated area and actual irrigation water use in Wadi Hadramout in 2005			
Irrigated crop	**Irrigated area (ha)**	**Actual irrigation water use (m^3/ha)**	**Total irrigation water use (MCM)**	**Share in total (%)**
Alfalfa	2,869	16,000	45.9	43
Wheat	3,932	6,500	25.6	24
Onion	1,188	13,096	15.6	15
Bananas	209	27,037	5.7	5
Dates	5,291	1,000	5.3	5
Mango	178	26,339	4.7	4
Tomatoes	239	7,389	1.8	2
Potatoes	168	6,946	1.2	1
Garlic	90	12,016	1.1	1
Total	14,164	7,533 a)	106.7	100

a) Total irrigation water use seems to be low compared to table 3.1.

Since qat, fruits and vegetables and alfalfa have a relatively high irrigation water requirement and a substantial share in the cropping pattern, they are the main irrigation water users. Special attention is therefore be paid to changes in policies that reduce the profitability of these crops.

5.2.2 Methodology to assess the implications of changes in prices

Whether changes in the policies that affect input and output prices will provide incentives to reduce groundwater extraction will be studied on the basis of a more quantitative analysis. The cost of pumping and delivering groundwater will be compared to the value of groundwater in irrigated agriculture. 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 will be required. This will substantially reduce farm incomes which will be politically unacceptable.

Whether the costs of groundwater are low compared to the value of groundwater in each of the case study areas will be evaluated for various crops on the basis of crop budgets. Costs of production can in principle be observed directly or derived from financial data.

The value of water, by contrast, must be estimated, as water is not actively traded on a market. Here, we take the average value of irrigation water as the net value added by the farmer per unit of water applied. By subtracting the cost of production from the gross production value, the net value added per unit water applied can be calculated. This is the value to irrigators of the groundwater they use or in other words the returns to water.

This approach is the one employed by most analysts and known as the Residual Method. Young (2005) provides an extensive review of the Residual Method, detailing its theoretical foundations, uses, benefits and limitations. 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, 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'.

It is important to note that 'net returns to water' are difficult to compute precisely for a number of reasons. Firstly, the precise technical coefficients (yield per hectare, water use, et cetera.) 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 require identification of marginal and average 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 because farmers are trying to maximise the return to the scarce resource.

5.2.3 Cost of groundwater abstraction as a function of depth of pumping

According to the literature (World Bank, 2006) the unit cost of pumping groundwater (USD per m^3) in the Sana'a Basin increase as follows with the depth of pumping: at a depth of 100 m, 200m and 400m costs are respectively USD0.15, USD0.21 and USD0.28/m^3 (see table 5.5).

Table 5.5	Calculation of the unit cost of pumping from the aquifer at different depths		
	100m	**200m**	**400m**
Drilling cost (USD)	9,000	20,000	44,000
Lifetime (hr)	80,000	80,000	80,000
Depreciation cost (USD/hr)	0.11	0.25	0.55
Pump investment cost (USD)	14,500	16,000	16,000
Lifetime (hrs)	40,000	40,000	40,000
Depreciation cost (USD/hr)	0.36	0.40	0.40
Diesel engine cost (USD)	16,850	18,350	18,350
Lifetime (hrs)	40,000	40,000	40,000
Depreciation cost (USD/hr)	0.42	0.46	0.46
Total capital cost (USD/hr)	0.90	1.11	1.41
Maintenance cost (USD/hr)	0.25	0.28	0.23
Diesel cost (USD/hr)	1.40	1.75	2.28
Lubricant costs (20% diesel cost)	0.28	0.35	0.46
Labour cost (USD/hr)	0.20	0.25	0.25
Total O&M cost (USD/hr)	2.134	2.625	3.205
Total capital and O&M cost (USD/hr)	3.03	3.73	4.61
Well discharge (litre/second)	5.5	5	4.5
Well discharge (m^3/hr)	19.8	18	16.2
Total cost of pumping (USD/m^3)	*0.15*	*0.21*	*0.28*
Source: Mid-Term Assessment Final Report ,18 October 2006 for the Sana'a Basin prepared by World Bank Team.			

Table 5.6 shows the breakdown of the unit cost of pumping in USD per m^3. It shows that total costs consist mainly of diesel and lubricant costs (about 60%) and capital costs (about 30%).

Table 5.6	Breakdown of the unit cost of pumping in USD/m^3 for the different components		
	100 m	**200 m**	**400m**
Capital cost of pumping (USD/m^3)	0.05	0.06	0.09
Maintenance cost (USD/m^3)	0.01	0.02	0.01
Diesel and lubricant cost (USD/m^3)	*0.09*	*0.12*	*0.17*
Labour cost (USD/m^3)	0.01	0.01	0.02

Given the current diesel price of YER35/litre or USD0.176/litre, the amount of diesel required to pump one m^3 of water can be calculated (by dividing the diesel and lubricant costs by the diesel price). The quantity of diesel required to pump water from a depth of 100, 200 and 400m is respectively 0.49, 0.67 and 0.96 litre per m^3. These figures are rather comparable to the figures used by Al-Hamdi (2002).

To be able to calculate the costs of pumping at various depth of pumping in the three case study areas, the unit cost of groundwater pumping are estimated as a function of the depth of pumping on the basis of the figures shown in table 5.5. Figure 5.1 shows that the unit costs of pumping (y^a) are increasing with well depth (x), but at a decreasing rate. The following relationship has been estimated: $y^a = 0.0194\ x^{0.448}$

Figure 5.1 **Unit cost of groundwater pumping as a function of the depth of pumping**

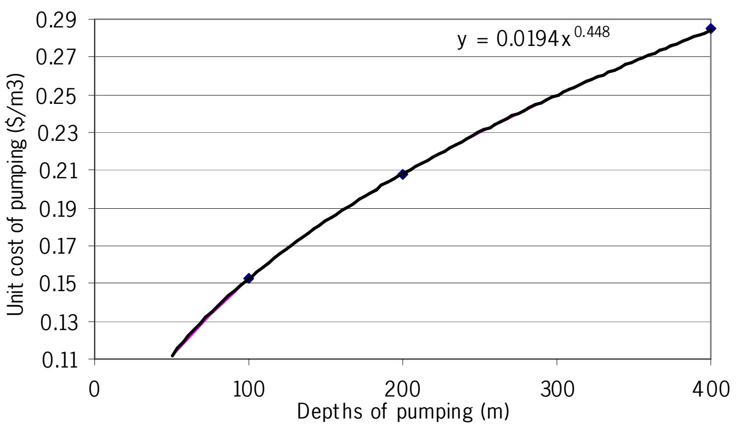
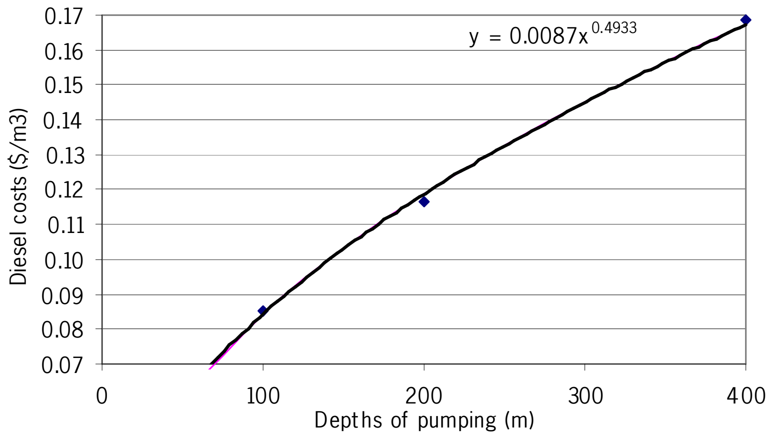


Figure 5.2 shows that the diesel and lubricant cost (y^b) are also increasing at a decreasing rate with well depth (x). The following relationship has been estimated: $y^b = 0.0087\ x^{0.4933}$

Figure 5.2	Diesel cost of groundwater pumping as a function of the depth of pumping



These relationships can be used to calculate the costs of groundwater pumping in the three case study areas. Although the depth of pumping varies largely within basins the following average depths of pumping are assumed: 180m in the Sana'a Basin, 94m in the Taiz Basin and 63m in Wadi Hadramout. These depths are based on the results from the field surveys (see table 4.2). This means that the unit costs of pumping are respectively USD0.20, USD0.15 and USD0.12 per m^3, while the diesel costs are respectively USD0.11, USD0.08 and USD0.07 per m^3.

These figures are conform other unit cost of pumping found in the literature (which show unit cost of USD0.21 per m^3 at 100m depth and USD0.25 per m^3 at 200m depth in Sana'a, USD0.19 per m^3 at a depth of 140m in Taiz and USD010 per m^3 at a depth of 150m in Hadramaut).

As the profitability of irrigation depends on the assumption made regarding average depth, the sensitivity of the results to this assumption made will be studied in more detail later on. As returns to water vary a lot among crops, a change in the costs of water may affect the profitability of some crops more than others. It is therefore likely that some crops can no longer be profitably grown at certain pumping depth. It will be shown at which particular depth of pumping it is no longer profitable to irrigate a particular crop (as returns to water and costs of water break-even). This is of interest as water tables in some aquifers are lowered by 6 meters on average a year - which might even be accelerated in the future.

5.2.4 Crop budgets and the implications of changes in prices

The crop budgets of the crops with high shares in total irrigation water use are presented for the Sana'a Basin, the Taiz Basin and Wadi Hadramout in Tables 5.7, 5.8 and 5.9 respectively. The data come from various sources, among other the statistical year book 2006. It is important to note that data vary a lot among years and have therefore been compared to other years as well and adjusted in case of an extreme bias.

Table 5.7 shows high returns on land (in USD per hectare) and water (USD per m^3) for qat, grapes, tomatoes and potatoes in the Sana'a Basin. Net returns to water vary among crops with values between USD0.18 and 1.13 per m^3, while the unit costs of pumping water are USD0.20 per m^3. This means that increasing the costs of water, might trigger substitution of crops with a relatively low return to water by crops with a relatively high return to water. The ratio between the value of water and the unit cost of water ranges from 5.6:1 for qat to 0.9:1 for alfalfa. This is an approximate estimate of the water cost/price increase required to drive a particular crop out of production. As the cost of water is far below the value of water for qat, grapes, tomatoes and potatoes, it is unlikely that policies that double the costs of water will substantially reduce groundwater use.

The total costs of pumping water can be calculated by multiplying irrigation water applied by the unit cost of pumping water and has a rather high share in total production costs. For qat costs of water are USD2,500 per hectare, which is about 80% of total production costs of USD3,180 per hectare.

Table 5.7	Crop budgets of qat, grapes, tomatoes and potatoes in the Sana'a Basin				
	Qat	**Grapes**	**Alfalfa**	**Tomatoes**	**Potatoes**
Gross production value (USD/ha)	14,823	6,612	3,000	6,060	4,480
- yield (kg/ha)	900	8,700	18,750	20,200	11,200
- price (USD/kg)	16.47	0.76	0.16	0.3	0.4
Costs of production (USD/ha) excl. costs of water	680	708	375	793	531
- costs of fertiliser, pesticides, clay (USD/ha)	354	381	202	427	286
- costs of labour (USD/ha)	326	327	173	366	245
Net production value (USD/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 (USD/m^3) or value of water	1.13	0.69	0.18	0.92	0.73
Costs of pumping water at a depth of 180m (USD/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*

Table 5.8 shows high returns on land (in USD per hectare) qat, onion and mango in Taiz. Net returns to water vary among crops with very low returns for sorghum (which is grown to be self-sufficient in their own sorghum demand). The ratio between the value of water and the unit cost of water (USD0.15 per m^3) ranges from 7.5:1 for qat to 0.2:1 for sorghum. Where the value cost ratio is smaller than 1, costs of pumping water exceed the value of water. Policies that triple the costs of water have a limited impact on qat, onion and mango assuming, of course that the output prices are unchanged.

Table 5.8	Crop budgets of qat, onions, sorghum and mango in the Taiz Basin			
	Qat	Onion	Sorghum	Mango
Gross production value (USD/ha)	11,970	4,500	238	10,990
- yield (kg/ha)	700	15,000	720	15,700
- price (USD/kg)	17.1	0.3	0.33	0.7
Costs of production (USD/ha) excl. costs of water	680	720	30	680
- costs of fertiliser, pesticides, clay (USD/ha)	354	387	13	354
- costs of labour (USD/ha)	326	333	17	326
Net production value (USD/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 (USD/m^3) or value of water	1.13	0.62	0.03	0.55
Costs of pumping water (USD/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*

Table 5.9 shows relatively low returns on water in Hadramout. The ratio between the value of water and the unit cost of water (USD0.12 per 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).

The current subsidy on diesel for irrigated agriculture decreases the unit cost of pumping water. Farmers paid a price of YER35 per litre of diesel in 2007, which is only USD0.177/litre. The price was raised in 2004 from 17 YER per litre to YER35, but diesel is still subsidised. A substantial share of the national budget (25%) is spent on diesel subsidies and 8% of GDP. In May 2008 farmers already paid YER50 per litre. The impact of a higher diesel price of say USD0.35/litre (or YER70/litre) will double the diesel costs (upward shift of figure 5.2). Diesel costs will increase by respectively USD0.11, USD0.08 and USD0.07 per m^3 and the unit cost of pumping will become respectively USD031, 0.23 and 0.19 per m^3. This may reduce groundwater use in Hadramout. It is, however, not likely that it will affect crops with a high return to water, like qat, grapes, tomatoes, potatoes, mangos and onions. It may trigger substitution of some crops with low returns to water by crops with high returns to water.

Table 5.9	Crop budgets of alfalfa, wheat and onions in Wadi Hadramout		
	Alfalfa	**Wheat**	**Onions**
Gross production value (USD/ha)	3,188	1,800	4,500
- yield (kg/ha)	18,750	3,000	15,000
- price (USD/kg)	0.17	0.6	0.3
Costs of production (USD/ha) excl. costs of water	413	400	345
- costs of fertiliser, pesticides, clay (USD/ha)	222	300	186
- costs of labour (USD/ha)	191	100	159
Net production value (USD/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 (USD/m^3) or value of water	0.12	0.2	0.32
Costs of pumping water (USD/m^3)	0.12	0.12	0.12
Value/Cost Ratio	*1:1*	*1.7:1*	*2.7:1*

In the same way changes in output prices can be assessed. It is clear that the gross and net returns to land and to water are very sensitive to these price levels. Nevertheless under a 50% reduction in the output price of qat, it is still profitable to grow qat. The benefits and costs of some other crops, like grapes, tomatoes, potatoes and mango will almost break-even under a 65% reduction in the output price. While sorghum will probably only be grown for non-economic reasons, for instance to be self-sufficient in their own sorghum demand. Such subsistence farming is often cross-subsidised by benefits from more profitable crops like qat.

It becomes clear that the implications of economic incentives on water are not so easy to assess as farmers will not always behave in a rational manner. Besides the crop budgets have shown that there are big differences among crops in their responsiveness - in terms of a reduction in groundwater use - to various incentives that affect input and output prices. This also means that the suitability of a policy that gives a certain incentive in a particular region depends a lot on the composition of the cropping pattern in that region.

In sum, 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). Besides a very substantial reduction in the output price of qat will not reduce groundwater extraction (under an approximately five times smaller qat price benefits and costs will break even). This will reduce rural incomes substantially and is therefore politically sensitive. In other words economic instruments that change the incentive structure at the farm level can *trigger* farmers to use less water and use it more productively, but it will be hard to substantially reduce groundwater use through such policy instruments. Such interventions are not the basis for bringing about a balance between supply and demand. If input and output incentives cannot achieve a balance between demand and sustainable supply, there are two options - either the balance is achieved by default as wells dry up (and the irrigated area can not be maintained), or collective actions at the local level must enforce reductions in use.

5.3 Improved irrigation technology and implications for water saving

5.3.1 Technical background information

To study the impact of improved irrigation technology - which is currently the cornerstone of donor policy - on water savings in Yemen requires some technical background information. The current subsidy programmes for improved irrigation equipment, like provided under the groundwater and soil conservation project of the World Bank, reduces the capital costs of investments in modern irrigation technologies. Some projects even subsidise 70% of the investment costs of adopting drip at the field level. These projects assume/claim to save large quantities of water and greatly increase the productivity of water.

For the purpose of our study a note was prepared assessing two aspects of the substantial ongoing investment projects in improved irrigation technology - first, the extent to which such investments will actually extend the life of the Sana'a Basin aquifer, and second questioning whether claimed water savings are actually real. The original note is included as appendix 5.

Subsequent exchanges with donors - especially the World Bank - were constructive and extensive (in excess of 100 emails). The first point made in the note, that the extension to the life of the Sana'a Basin aquifer would be a matter of a few years was not challenged (and indeed is consistent with more detailed analysis in JICA 2007).

The second point, regarding the extent of 'real water savings' was more controversial, and the World Bank proposed a number of scenarios in which water savings would be achieved - for example where aquifers were polluted, where evaporative losses are high, or where capillary rise was prevalent. It was agreed that in future it would be appropriate to assess every individual site where improved technology is proposed to assess the likely disposition of flows before and after the introduction of improved technologies. This is a significant policy change.

An additional point of discussion was the extent to which improved irrigation technology allows higher productivity of water. This issue has a number of components: first, if improved technology allows farmers to change from low value field crops (wheat, maize) to higher value crops (fruit, vegetables) then there is an economic gain. This of course raises the issue identified in GW-MATE 3 and Bosworth et al. (2002), namely that incentives to pump are actually increased by this change.

Second, in some cases farmers may practice controlled deficit irrigation when improved technology allows more precise scheduling and application of water. While the predominant relationship between yield and beneficial consumption is essentially linear, it is possible with very careful management (Goldhammer et al., 2008) to reduce water consumption by more than the fall in yield per hectare and consequently increase the productivity of water.

In Yemen, as elsewhere, this may be possible, but a number of caveats are relevant:

- the relationship is uncertain for important irrigated crops in Yemen (Qat, for example - which is irrigated infrequently and heavily to induce new shoots.);
- farmers only pursue such strategies when they are short of water - and the impact of the improved technology is to increase the beneficially usable water supply at farm level. As long as farmers are pursuing maximum income per unit land, they will tend towards full irrigation strategies;
- practicing deficit irrigation requires a very high degree of management competence. Farmers must be fully confident that the reduced supply during stress periods is appropriate in timing and quantity (which means knowledge of soils as well as plant physiology) and able to apply this knowledge by precise on farm water management.

Finally, leaving aside the question of whether the extra water would have been a recoverable loss or not, it is accepted that improved irrigation technology delivers more water to the field per unit of water pumped - and hence delivers a private benefit to the farmer. The question arises as to whether this is appropriate use of public subsidies.

So, in some parts of Yemen where irrigation water losses are recoverable, like in parts of Taiz and parts of Hadramout, improved irrigation technology will save less water than calculated (as 'losses' are re-used). In other parts like in parts of the 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 extent the lifetime of the aquifer by only a few years.

According to Lichtenthaler (2002) a reduction of groundwater abstraction may similarly be achieved by a non-intervention strategy. Indications are that within the next decade a large percentage of farmers will be forced to stop pumping. In this sense, irrigation support measures, as envisaged by the proposed programmes, may be even counter productive and prolong the process. All this may be doing is buying up time.

This view is also confirmed by Chris Ward a long-term observer of Yemen when he states: decentralisation and the partnership approach can only be viewed 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 dependent on water mining (Ward 2001).

According to Lichtenthaler (2002) the solution is clear: 'The extent of irrigated agriculture in the Sa'dah Basin has to be returned to sustainable levels. And livelihoods have to shift out of agriculture. Waves of migration have characterised the history of Yemen and we may not assume that we have the power or the wisdom to change this.'

5.3.2 Evidence from the field

Various projects in the irrigation sector have aimed to reduce the overdraft of aquifers through improved technology. It consists of hardware (replacing open earthen conveyance channels with pipes, and replacing traditional technology with on-farm drip or bubbler systems) and software through an Irrigation Advisory Service (recommending improved schedules, appropriate quantities, and crops that are more productive per unit of water consumed).

In this section the impact of improved irrigation technology is addressed. It looks at evidence from the field and builds upon findings of other studies. The Report on Evaluation of Water Savings and Groundwater and Hydrometeorological Observations[1] provides the basis for the analysis. Similar claims of water saving and increased yield are made in other documents.

The report assembles information from eight Field Units covering 27 different cropping patterns and a total of 18ha (page 12). Water savings and yield increases resulting from replacing the earthen conveyance channels by pipes, and replacing traditional field irrigation techniques by drip/bubbler systems are reported. The results are impressive and the average percentage changes in key components of the farm budget are summarised in table 5.10.

Table 5.10 **Initial Results from Pilot Farm Units on Water Saving and Crop Yield (in %)**

	Water Applied	Fuel	Pumping Hours	Labour	Crop Yield	Fodder Yield
Pipe vs Open conveyance Channel	-17	-24	-21	-28	+16	+15
Modern vs Traditional on-farm irrigation technology	-32	-33	-33	-32	+13	+15
Combined	-44	-49	-47	-51	+31	+32

The report is appropriately cautious about extrapolating these short-term results from relatively small areas with intensive supervision - but the results are taken as indicative of the potential of these technologies to change on-farm irrigation economics dramatically.

In the pilot areas, the productivity of water (Water Use Efficiency) increases by a factor of 2.3.[2] This figure is critical because it 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 (for the same cost in fuel and labour) almost twice the area AND get 30% more production per unit area.

From the farmer's perspective this is clearly an excellent new technology, as it increases the profitability of abstracting water from the aquifer considerably.

From the resource perspective, the situation is not so clear. The report repeatedly uses the term *Net Water Savings.* Comparing water delivered by the well with traditional technology to water delivered with modern technology is a

[1] Republic of Yemen MAI, Groundwater and Soil Conservation Project (IDA Credit 3860 - YEM) Undated.
[2] Productivity = crop production/water use = (1+0.31)/(1-0.44).

measure of *gross* water saved, but only a hydrogeological assessment of where the large quantities of 'saved' water were previously going can firmly conclude the extent of *net* water savings. The situation is not black or white - inevitably some water is lost to non-beneficial evaporation, especially near earthen water courses - but extensive literature on this topic[1] points to extreme caution in assuming that the difference between 'before' and 'after' deliveries is an accurate indicator of savings available for alternative use. An appropriate analysis is critical if resource planners are to be provided with useful planning data. This position is entirely endorsed by the GWMATE approach, sponsored by the World Bank.

However for the *farmer*, the 'savings' in pumping charges, labour, wear and tear on his machinery, time, et cetera are real and strongly increase the profitability of pumping. The 'savings' he experiences provide the scope to reduce his expenditure, or to maintain his pumping rate and increase his irrigated area.

This issue is addressed in the project: farmers who receive subsidised equipment must agree not to expand their irrigated area with the 'saved' water. Nevertheless, the report from the pilot areas indicates (page 20) that on average irrigated areas have already increased by 10% (range 0-22%). While this may be interpreted as broad compliance with the project 'rules', it is important to note that (a) farmers might wait a year or two to be sure that they really would have the potential to irrigate more land before making the investments required; (b) farmers may not have any additional land to expand onto; and (c) if expansion at the rate of 10% per year is happening on these closely monitored pilot areas, the prospect for controlling expansion on a wide scale is doubtful - indeed since farmers already buy and sell water among themselves, selling 'savings' to non-participants in the programme would seem to be unmonitorable. Finally, once the project period is over, it is not clear who will enforce the agreement. The field survey (see chapter 4) showed indeed that about 15-20% of the farmers would expand the area if they had extra water available.

For the *aquifer* the issue distinction between *net* and *gross* water savings is critical. What is actually happening to the 'excess' deliveries applied through traditional techniques? In the course of this study, an extensive debate developed around this topic, and also on the topic of increased productivity.

On both issues the situation is open to debate. Under the complex hydrogeological conditions of Yemen, return flows from excess irrigation deliveries

[1] See Seckler, D. *The New Era of Water Resources Management: From 'Dry' to 'Wet' Water Savings* for an overview (www.worldbank.org/html/cgiar/publications/issues/issues8.pdf) Perry, C. *Efficient Irrigation; Inefficient Communications; Flawed Recommendations* for a review of the literature.

(or seepage from delivery channels) may not reach a 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: 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.

The field survey produced strong supporting evidence of this: in Sana'a, for example, the distribution of wells is strongly bimodal. There are a lot of relatively shallow wells (about 20% are less than 40m deep) and a lot of deep wells (about 70% are more than 150m deep).

Regarding the other 'loss' - non-beneficial evaporation (E) - evidence from the literature[1] generally suggests that if irrigation is reasonably well managed, E is rather small and difficult to reduce. If irrigation is strongly localised 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 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, would be substantial (but most conveyance systems of any length are already piped).

The conclusion on both these issues is that there are *net* water savings (as defined by GWMATE and ICID) from improved irrigation technology, but they are likely to be significantly smaller than the *gross* water savings assessed on the basis of measured deliveries.

A second issue, which proved more contentious, centred on whether the productivity of water can be increased significantly. Most peer-reviewed scientific papers argue that biomass formation is a linear function of transpiration, so that yield increases are generally the direct result of the increased transpiration resulting from a better irrigation service. Nevertheless, deliberate stressing of certain categories of crop at specific periods in the growth cycle does result in increased water productivity, and field data from China confirm this for grain crops under excellent management and strictly limited supplies. Whether Yemen - and crops such as a qat, grapes and vegetables and yet to be enforced quantitative restrictions - meets these conditions remains to be demonstrated.

[1] Evaporation Research: Review and Interpretation; Burt, C.M., A.J. Mutzinger, R.G. Allen and T.A. Howell, Journal Of Irrigation And Drainage Engineering, ASCE, January/February 2005.

In considering this important issue, the context is critical: in China, farmers are *first* persuaded to accept reduced water deliveries to the field. *Then* they are assisted to find better ways to utilise that resource through improved irrigation scheduling, planning dates, or crop selection. In Yemen, the introduction of improved technology first *increases* the availability of water at the field, and the farmer is then to be asked (a) not to use the extra water available, and (b) recommended to *decrease* water use such that his production will actually fall (the case for deficit irrigation is that a reduction of 20% in water used may only cause a 10% reduction in yield per unit area) with a consequent increase in yield per unit water. Consequently, from the farmer's perspective he is asked to invest in new technology, reduce water consumption, and (possibly) to reduce production because he is not 'allowed' to extend his irrigated area and reap any benefits of increased water productivity.

Another calculation in the note setting out these issues has not been challenged. This indicated that if the reserves in the Sana'a Basin amount to ten years consumption at current levels, then the aquifer's life would be extended by only three further years if the technology works perfectly and saves water to the extent claimed. This conclusion was subsequently found to be consistent with the far more detailed JICA review of the hydrology of the Sana'a Basin, which reached essentially the same conclusion and further pointed out that sustainable water use in the basin would require a 70% reduction in the irrigated area - provided all else worked perfectly in terms of recovering return flows, et cetera. An irrigation efficiency of 90% is assumed in this scenario.

To summarise, it is certain that the new technologies make pumping far more affordable and profitable than traditional technologies for farmers. It is consequently certain that controlling pumping, areas, and cropping patterns will become far more difficult to enforce in future.

The JICA report suggests that equilibrium in the Sana'a Basin requires a 70% reduction in irrigated area if all possible savings in irrigation are achieved. For Taiz and Hadhramout the figures would be 50 and 87%, respectively based on current irrigation technology. *If* the reported pilot Farm Units savings are achievable, then Taiz might be able to maintain its current irrigated area. Given that aquifers in Taiz respond to rainfall (and hence recharge from 'losses' is likely to be effective there) this is an optimistic scenario (as *net* savings from modern technologies are smaller than *gross* savings). For Hadhramout, the irrigated area must be severely curtailed - with or without savings - but the time available to achieve this is much longer, because the estimated volume of water available in this aquifer is much greater than in Taiz or Sana'a. The recent (April 2008) GW-MATE mission placed particular emphasis on the need to evaluate the economic reserve in the various aquifers in Yemen as a basis for planning and prioritising interventions.

Nature's capacity to ensure a balance between supply and use is, however certain. Forty years ago, water use in Yemen was a balance between rainfall and usage - for rainfed crops, spate irrigation, and naturally recharged aquifers. That balance will be restored at some point. For many areas in the Sana'a Basin, and to a lesser extent in Taiz, the timeframe for natural equilibrium to be restored is short - farmers are already abandoning their land in some places.

5.3.3 Agricultural Impact of Improved Irrigation Technology

Tables 5.7, 5.8 and 5.9 show available crop budget data based on water requirements using traditional technology for the main crops in the study areas. Some crops have relatively low returns[1] (Alfalfa in Sana'a and Hadramout; Sorghum in Taiz). These crops are either grown for home consumption or as feed for livestock, and are therefore less sensitive to changes in the profitability. For the other crops, the value of water in Taiz and Sana'a is 4-9 times higher than the cost of pumping.

It is essential to realise that these ratios are for traditional irrigation techniques: the new techniques, which effectively lower the cost of water by 44% and increase its productivity by over 30% imply value:cost ratios in the range of 10-20:1.

While doubts remain about the extent of the positive impact of new technologies on aquifers, the observed changes in the profitability of irrigation to the farmer are clear and undisputed.

Conclusions - Resource Sustainability

It is generally agreed that demand for water - manifested by over-pumping of existing wells, illegal deepening of wells and illegal construction of new wells - is out of control. Only local action by concerned groups is (in some areas) restraining further expansion of well capacity and irrigated area. An over-simplistic statement of the situation would run as follows:

Changes to national incentives (for example by increasing the price of diesel, or finding some way of charging for water) would make irrigation unviable in Hadhramout before impacting significantly on demand in Taiz or Sana'a. Further, the increases necessary to impact significantly on the profitability of Qat would render all other irrigated agriculture non-viable.

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

In fact, of course, a change in one price results in a new equilibrium of all prices, and as such the changes would be *in the directions indicated* rather than to these extreme positions.

However, this is the predictably difficult situation while the value of water is 'only' 4-9 times the cost of pumping. The implications of the results from the pilot Farm Units is that this ratio could rise to 10-20 times if farmers use new irrigation technology.

For aquifers with a relatively short remaining life it has been demonstrated in an earlier note (see appendix 5) and confirmed by the JICA review of the Sana'a Basin that the achievable extension of aquifer life through improved technology is limited - perhaps three or four years.

The GW-MATE mission of April 2008 is clear on the importance of this issue stating (Table 1, page 3): *Urgently needed to estimate economic storage as starting point for preparing a GWMAP for each pilot groundwater management body.*

GW-MATE also has estimates of the ratio between recharge and current abstraction. For Taiz, this is estimated at 50%, for Hadhramout 13%, and for Dhamar 7%. The recommended approach from GW-MATE to these situations is:

- *For Taiz*

  Implement sustainable irrigated agriculture on a surface close to the currently irrigated area (only if GW is used more efficiently through 'real water savings' and crop pattern changes, provided horizontal & vertical expansion as well as abstraction from existing wells and new drillings are controlled).
- *For Hadhramout and Dhamar*

  Buy time to transform to a less water - demanding economy, through drastic reduction in irrigated area where same demand-management and control measures as in Taiz should be implemented
- *For all*

  Provide sustainable drinking water sources (only if strict measures to protect the quality of the resource, ensure sound well drilling and construction practices and protect well heads are enforced)

In areas where a majority of farmers will no longer be irrigating in less than ten years, the priority is to prepare for the new economy (a post-irrigation scenario) that is certainly coming - with or without improved irrigation technology.

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 no doubt devise novel approaches to their situation.

But the remaining aquifer life is critical, and in this context, from two perspectives: First, where the remaining life is short, is it worth subsidising further in improved irrigation technology? 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? Third, if limited funds are available for support, 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?

5.4 A review of the options

In sum, current policies lower the costs of power and consequently the cost of water by means of a subsidy on diesel - making irrigation more profitable. Investment in improved irrigation equipment is subsidised - which again makes irrigation more profitable while potentially saving power. The output price of the main water-intensive crop qat is high and protected by the obstacles to qat imports.

To repeat the point made in the DPR: conserving groundwater, sustaining the rural economy, transferring water to higher value uses, and addressing poverty are generally conflicting objectives. Adding to this the DPR's projection that fruit and vegetable production should increase for export purposes does not help.

In fact, any intervention that decreases profitability of irrigation water use in order to decrease water demand must in consequence decrease farm incomes. This is true whether the cost of water is increased (e.g. by raising the price of diesel), or the price of crops is decreased (e.g. by importing qat). 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 direct to farmers to offset their lost income, by identifying alternative, higher value crops, or by government support to the price of competing, less water-consuming crops. Information available gives no cause for optimism:

- the introduction of compensatory payments would be administratively complex and open to misuse. It is widely agreed that the administrative capacity of the government is not strong, and that regulations are not well observed;
- farmers already achieve exceptionally high returns to water by international standards, especially for qat. The scope to increase incomes by shifts in cropping pattern (other than converting more non-qat areas into qat, which is happening in any case) is limited. While some reallocation of resources to more productive uses may be feasible, the context will generally be one of falling agricultural incomes: if there is a way of making more money from available resources in the existing market, then farmers would already be exploiting this option; if there are innovations that farmers are not aware of, then none has been mentioned to the team preparing this report;
- a crop subsidy programme - given the difficult state of the country's finances - is unlikely to be affordable, and would be difficult to target.

Other recommended approaches, frequently referred to in donor reports, include the introduction of tradable water rights and/or water markets, and saving water through improved irrigation technology. These two issues merit careful analysis.

Water markets are already active in Yemen. Well-owners sell water to neighbours and also to tankers that transport the water to distant users[1] (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 therefore 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, virtually no 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 entitle-

[1] In the course of this study, though not adequately documented, it was found that the price differential between what the well owner charged, and what the water was sold for to the final user was a multiple of 5-10, which seemed high. Further thought suggests that this is logical: to deliver 25 cubic meters of water from a rural well to a town involves several hours' transport with a large truck, and possibly distribution via smaller trucks. An implication of this calculation (which certainly needs further refinement) is that doubling the price at the well only raises the price of delivered water by 10-20%.

ments, enforced by the rule of law is an exceptionally difficult task, in which many countries are failing (see literature review). Encouraging water markets in the absence of defined rights is simply wrong - and evidence that some tribal leaders are banning water exports is confirmation that this fact is already understood by those affected.

Beyond this, the question of whether farmers will be prepared to invest (at least partially) in modern technologies, and then prevented from reaping the primary benefit that can be derived from this - to increase production by increasing consumptive use - remains to be tested.

Certainly, unqualified claims of water savings of thousands of cubic meters per hectare are misleading to policymakers and often, if not always, factually incorrect. Future investments may be justified on the basis of energy savings (which are real, and beneficial - but have the unfortunate side-effect of making beneficial consumption cheaper), together with a local analysis of the extent of water savings in the specific hydro-geological context. This would be a step forward but not a solution.

Exchange rate policy has seen the Yemeni currency maintain stability against the dollar since 1996. According to the DPR, this Yemeni currency should be declining - but the report was written in 2006, prior to the recent dramatic fall in the dollar (which effectively devalues the Rial internationally) and rise in the price of oil, which supports a higher exchange rate.

Importing qat has been on the agenda in Yemen for some time, and is specifically mentioned in NWSSIP. 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 solely for export, and the revenues distributed among the Yemeni farmers who would reduce their qat production.

A study is underway between the FAO and Ministry of Agriculture and Irrigation (MAI) on this proposal, but the team has been unable to obtain any information. For the purposes of this analysis, we assume the following:

- qat can be grown much more cheaply in Ethiopia;
- the quality would be acceptable to Yemeni consumers;
- the output would be targeted at the lower quality/high volume Yemeni production;
- qat would be grown without excessive use of pesticides (which is a health hazard to consumers in Yemen).

The benefits of such a scheme include the positive health impact of reduced exposure to pesticides; potential savings in water if local production is reduced; and compensatory revenues to farmers who stop pumping.

Implementation issues include the problem of overcoming vested interests in the qat market; ensuring that there are actual water savings (for example, if a farmer whose well was about to dry up 'signed up' for the cooperative venture in Ethiopia, the actual water savings would be far less than implied by assuming that his current level of use would continue indefinitely).

Hence, ensuring the link between a share in revenues from the Ethiopian venture and actual reductions in water use is difficult - but beyond the difficulties of implementing this linkage, what are the implications of allowing qat imports?

First, importing cheap qat will lead to an increase in qat consumption, which would directly undermine alternative strategies aimed at reducing qat consumption by limiting the days of use, banning public consumption, banning use by civil servants during working hours, age restrictions, and so on.

Leaving these implementation issues aside, in economic terms, substantial imports of cheap qat would be expected to lead to the following:

- an increase in total consumption, but a decrease in domestic production and consequent water saving but also lower rural incomes *unless;*
- the profit from domestic production is so high that farmers can compete with imported qat (perhaps charging a premium for fresher 'local' produce);
- in either event, domestic prices will fall and all qat producers will be worse off (except, perhaps those compensated by revenues from the Ethiopian venture).

Complex issues arise: if we assume that imported qat will render pumping from a specific depth unprofitable (just as it is currently unprofitable to pump for low value crops from deep wells), then the water below that depth is preserved for future use (in passing, we note that improved irrigation technologies will allow pumping from deeper). If the aquifer is fossil (ie not recharged), then what interest is being served by preserving it? There is no necessary relationship between the economic pumping depth at some new qat price and the required quantity (and indeed location) of water required for domestic use. 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.

Consequently, one certain impact of allowing importation of qat is that rural incomes will fall - and the corresponding benefit (if domestic water use can be preserved more efficiently by other means) is unclear.

So, modification of agricultural and food trade policies - can influence demand for water by making water - intensive crops less attractive. It may also restrict potential returns from groundwater by preventing export of high value crops. The impact of this is on the one hand to reduce the demand for water (positive impact) while on the other hand reducing the benefits derived by the farmers from using the resource (negative impact on rural incomes). 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.

6 Conclusions and recommendations

Forty years ago, Yemen's water consumption was in balance with its available resources. Forty years from now, and often far sooner, that balance will be restored in many areas simply because the mining of reserves will have come to its natural conclusion as aquifers dry up, become saline, or become too expensive to exploit. That process is already underway and farmers are leaving the land.

A range of interventions is possible - but although the literature and economic theory suggests the range is wide (water pricing, metering, water rights, water markets, targeted taxes, subsidies and incentives, information, participatory management, et cetera), the range of potentially effective interventions in the Yemeni political context is far more limited.

Persuasion based on information is a universal priority. At the national level, a 'water budget', setting out which activities use how much water would be powerful in mobilising 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 central government (and concomitant strength of local traditional institutions). If local forces are to be mobilised to address local issues, the foundation for their actions will be awareness: how much water do they have; where is it going? Currently the information emphasis is on 'savings'. Whether the advertised savings are correct 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. While frequent references are made to the need to strengthen these (including establishment of an Irrigation Advisory Service), little information is available about what messages should be conveyed. Possible topics include land-levelling, improvements to delivery channels and other low-cost interventions that farmers can undertake.

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 subsidised 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 other impacts that the government will consider simultaneously. The subsidies to improved irrigation technology are unnecessary.

Other conventional incentives (water rights, metering, water pricing, controlling pumping, et cetera) 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 hence 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 an exceptionally difficult task. Encouraging water markets in the absence of defined rights is simply wrong. However, if local groups are persuaded that self-regulation is critical, some forms of regulation may evolve. Again, the first priority is the information base that will persuade local groups to act, and help them formulate actions that have the outcomes they desire.

Indirect incentives such as education or training for farmers leaving agriculture will have a role if it is accepted that the agricultural future for a significant number of farmers is bleak.

Regulation has limited prospects for success (again, as a government-administered scheme). The objective of this report was to review incentives - primarily economic incentives - that affect demand for water. A dominant characteristic of Yemen, however, 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. Wells continue for instance to be drilled, and if reported are generally authorised. Indeed it can be argued[1] that the licensing process is essentially redundant because if local farmers are happy with the construction of a new well, it will be authorised; if they are not happy they will use traditional pressures to prevent construction - and if that does not work it is probably because the new well owner it too powerful to resist through official means. Hence, support to these community actions is recommended in this

[1] We are grateful to Gerhard Lichtentaeler for this insight.

study. Local communities and water user associations can play a big role in managing water in the best possible way.

A key element in this strategy will be the strong and explicit endorsement of what is required - for example cessation of agriculture in the vicinity of Sana'a to protect urban supplies - from the other end of the political spectrum, namely the president. Such endorsement would be powerful in supporting actions by rural elites, and would give the government agencies - especially NWRA - added credibility as they pursue their responsibilities.

But the situation is *location-specific*: it is predominantly true for the Sana'a Basin. 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: overdraft is estimated by GW-MATE to be double the recharge so the scale of irrigation will eventually decline substantially but there is recharge, and the sustainable level of irrigation may be significant locally.

In Hadhramout 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.

These locational differences 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. This will increase the need for domestic water and for water needed by industries and commercial activities that will provide new employment.

In Taiz the highest priority (as stressed by GW-MATE) 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? Where the potential for sustainable agriculture is significant, the priority is to manage the remaining resource.

In Hadhramout, while the level of over-abstraction is high, and a fuller understanding of local hydrogeology is needed, the remaining resource is very large.

Beyond the discussion of the impacts of technical innovation, issues arise regarding the allocation of resources. Whether water is saved or not, the financial incentives to invest in some level of water 'saving' (certainly piped distribution to fields, maybe bubbler and drip) are high because of the power savings. Should such investments be subsidised? A World Bank working paper[1] calculates the payback period for piped conveyance systems as one season (corresponding to less than two years with no subsidy). Clearly such innovations require no

[1] Financial Price of Water for Irrigation, Ahmed Shawki, World Bank (undated).

support from government or donors (indeed many, many farmers have already installed such equipment).

- If any subsidy is to be paid, should it go to farmers who will anyway be out of business soon as the remaining life of the aquifer is short (so why invest for just a few years' benefits?) or to farmers in an area where the remaining life is substantial (where the investment will pay off for many more years, and financial incentives are adequate to ensure private financing)?

Technical interventions therefore should be approached with caution, and there should be a significant additional reason to justify subsidies in this area. Dissemination of information is essential. It should stress not 'water saving', but the implications of consuming perhaps 30-50% of the nation's water reserves to grow qat. At the local level, support to initiatives by local groups to conserve and manage their resources - again based on a clear understanding of what the future holds and what improved technology can contribute - would seem to be top priorities in the sector.

Importing qat would (if the price is as expected far below Yemeni levels) reduce the demand for irrigation water substantially. In all likelihood, many of the areas now growing qat would not find another crop with similar returns (though if they did, the demand for water would not be much affected). Rural incomes would fall and the pace of exit from agriculture would (temporarily at least) rise.

Serious promotion of alternative water-conserving technologies (greenhouses) is unlikely to be at the pace required to impact substantially on agricultural income and employment - and the supporting infrastructure of marketing and distribution would require a massive investment with little real knowledge of the resource sustainability. It is probably better to allow this sector to develop naturally based on knowledgeable investors.

In the Yemeni context, the question is therefore not demand management - a very low renewable resource, extremely high (and increasing) value of water - together with limited institutional capacities to monitor, allocate and regulate - make demand unmanageable. The problem is addressing the needs of the large number of farmers who will leave the agricultural sector in the coming decade or so because the water will run out.

The priority is consequently not subsidising 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, depending on whether the controls can be enforced.

There are two higher priorities. First, to direct 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.

Second, to provide all possible support (information, advice, logistical support) to the rural communities that are prepared to address their problems as best they can, and decide how to approach the future.

A change of emphasis should be considered. It is conceivable that new crops, deficit irrigation, an improved extension service, research to optimise irrigation scheduling and so on will find solutions that extend the life of some aquifers. However, these gains are at best uncertain, will certainly 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 less than two one or three two decades, resources are probably best devoted to needs of ex-irrigators in the post-irrigation scenario.

To achieve the first priority - to direct resources towards 'buying out' or protecting water rights around major towns and cities so that water for domestic and non-agricultural use is available - 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 current situation of the aquifers especially regarding the remaining aquifer life (storage of water). It is therefore highly recommended to do a technical study to define the areas - for instance around Sana'a - required to be reserved for non-agricultural use. This will protect water supplies for the highest value use of all-domestic consumption.

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List of definitions and terms

The nature and role of economic instruments is complex. Discussion and debate can only be based on clear and mutually understood terminology, and we therefore summarise below the terms used in this report.

Charge
Includes all fees payable by the irrigator, which may be based on crops irrigated and/or volume of water received and/or fixed charges.

Price
The volumetric price of water - how much extra the irrigator pays per unit of water received. Often, with crop-based or quota systems, the marginal price is zero (even though the charge may be high) and once the farmer has decided to irrigate there will be no marginal incentive to save water.

Cost of the irrigation service
The expenses incurred by the supplying agency in providing the service. Precise definitions depend on local rules, but typically include operation, maintenance, staff and fuel costs, plus some elements of replacement costs and amortisation of capital.

Value of water
Incremental income received by the farmer as a result of irrigation services, divided by the quantity of irrigation water used.

Volumetric charging and market-pricing are closely related concepts
Volumetric charging occurs when the quantity of water provided is determined by an allocation procedure such as a quota, or water for an agreed cropping pattern, and the charge is based on the actual quantity of water delivered - but the farmer cannot simply demand as much water as he might wish to apply at the agreed price. Market-pricing implies that water is available at a set price, and the farmer decides how much water to take at that price.

Tradable Water Rights
Allow users with an assigned water quota to sell the quota to another user (or buy additional quotas from others).

Water use
Application of water to any specified purpose, comprising.

Consumed Fraction
Water evaporated or transpirated, comprising.

Beneficial Consumed Fraction
Water consumed for the desired purpose.

Non-beneficial Consumed Fraction
Wither evaporation or transpiration.

Non-consumed Fraction
Water not lost to the atmosphere, comprising.

Recoverable fraction
Water that can be recovered and re-used.

Non-recoverable fraction
Water that cannot be economically recovered.

Real water savings
Include only reductions in evaporation (that is consumptive use) and loss to saline water bodies, but not those reductions which would have generated aquifer recharge.

List of abbreviations

GDP	Gross Domestic Product
GTZ	German Technical Cooperation
IWMI	International Water Management Institute
KfW	German Development Cooperation
LEI	Agricultural Economics Research Institute
MAI	Ministry of Agriculture and Irrigation
MWE	Ministry of Water and Environment
NWRA	National Water Resources Authority
NWSSIP	National Water Sector Strategy and Investment Program
O&M	Operation and Maintenance
WB	World Bank
WEC	Water and Environment Centre
WUA	Water User Association
WUG	Water User Group

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Prof. Dr Chris J. Perry - has 20 years' experience in irrigation and water resources project design and implementation with the World Bank followed by 5 years' experience at the International Water Management Institute (IWMI) in Colombo, Sri Lanka. He has particular interests in the overall framework within which successful water management is practised; the economics of water and water management; performance assessment; and the potential of remote sensing to contribute to improved understanding or water systems.

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Dr Nasser Aulaqi is a professor of Agricultural Economics, Sana'a university, Yemen. Professor Al Aulaqi is a former minister of Agricultue and Fisheries in Yemen and former president at Sana'a University. He wrote numerous articles, books and other publications in the areas of economic development, water resource economics and food security issues. He received a PhD from the University of Nebraska, USA in 1974.

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Appendix 1

Summary of discussions with government officials

In order to get personal and official views and the latest thinking regarding water policies, plans and programmes from different government officials who deal with the water sector many interviews and meetings have been conducted A list of officials met can be found at the end of this appendix.

The serious water crisis has even been discussed with His Excellency, the president of Yemen over an extended period of time. The last time was on November 2007. The President seemed to be very much concerned about the problem and on several occasions he discussed the issue of water in his speeches. However, he indicated that it is the government responsibility to find solutions to the water crisis in the country.

Among the other officials met is the minister of Agriculture and Irrigation. He pointed out that he agrees completely with the water strategy and plan to implement those sections of the strategy regarding agriculture. He mentioned also that his ministry would give more attention to the improvement of water use in irrigation by providing farmers with modern irrigation equipment which would be financed from the Agricultural and Fisheries Production and Promotion Fund. He further stated that the fund's activities in the future would be broad-based rather than concentrating on building dams as was the case in the past.

The overall responsibility of the water sector regarding its management and regulation is in the hands of the Ministry of Water and Environment (MAE). A new minister was appointed more than a year ago. On March 18th, 2007 he had an interview with Althawra official daily newspaper in which he indicated that the government approved the water strategy more than two years ago but unfortunately nothing much happened since that time and he put part of the responsibilities on the agricultural sector including the Ministry of Agriculture and Irrigation. He pointed out in his interview that the Investment Program of the general directorate of irrigation in the ministry of agriculture is completely opposite to the Strategy since they are still planning to expand irrigated area in the country rather than slowing it.

He said that the Ministry of Agriculture and Irrigation is planning to construct more dams which he claimed to be of no important economic benefits and the Ministry's efforts to improve water management were very limited. He suggested that the ministry of Agriculture and Irrigation should give more attention to rain fed agriculture.

The Minister of Water and Environment indicated also that his ministry was enable to control the rigs and drilling of wells is continuing without permits because of the lack of cooperation from other government ministries and agencies. The Minister of Water and Environment praised the Social Fund for Development and the Public Works Projects for their cooperation with his ministry. These two government associations are working closely with the Ministry of Water and Environment to implement the water strategy by financing various projects in water harvesting and terrace improvements.

The Minister of Water and Environment proposed that a National Water Conference should be held to discuss the water problem in Yemen.

The Deputy Minister of Water and Environment Dr Mohammed Al-Hamdi was another important official met regarding our study. He repeated what he mentioned in various newspaper interviews. He said since Agriculture is the main consumer of water he suggested that the Ministry of agriculture should give more attention to rain fed agriculture and the improvement of water usage efficiency rather than continuing investing in water structures such as dams. He emphasised also the need for more coordination with the Ministry of Agriculture and Irrigation since the water law specified that dams and other water harvesting structures should be constructed only after NWRA approved them. He suggested that the a joint unit between the Ministry of Agriculture and Irrigation and NWRA should be established to perform studies on dams to be constructed in different parts of the country. He proposed that the Agriculture and Fisheries Production and Promotion Fund should finance waste water treatment projects to make it suitable for irrigation since this water is secured and could he readily available for irrigation. Dr Al-Hamdi is not very optimistic about the ability of different government institutions to effectively manage the water resource of Yemen because of the lack of coordination and cooperation between them regarding the implementation of the official Water Strategy of the government.

All the government officials met were very concerned about the role of qat in the fast depletion of Yemen ground water recourses but none of them was optimistic that there will be a drastic solution to the problem of qat because of the strong vested interests involved in the production and marketing of qat. Also most of the officials met thought a price hike in diesel will go a long way in reducing the quantities of water extracted for irrigation purpose but they all agree that the government will not be able to raise the price of diesel in the next two years because of the political opposition to such move.

The importation of qat was discussed with some officials but most of them thought such policy is not being discussed seriously at the present time since parliament will not approve such move by the government.

The directors and experts who run the Sana'a Basin Water management project, The Spate Irrigation Project, The rain fed and Livestock project and the soil and the water conservation project all agree that these kinds of projects are practical ways to solve the water crisis in Yemen. They claim that these projects are already saving millions of cubic meters of water every year. They also indicated that user groups are heavily involved in these projects and they are cooperating in the management of these projects in their efforts to reduce water extraction which resulted in the serious overdraft in many basins of Yemen. However, it is doubtful whether this kind of response from farmers will continue in the future when these projects are completed and no longer subsidised irrigation technologies adopted are provided to them.

Meetings with Donors/other interested parties. Initial meetings were held with various individuals with expert knowledge of the situation in the water sector, including:

- Dr Mohamed Al-Hamdy (Ministry of Water and Environment);
- Dr Gerhard Redecker (KfW);
- Dr Michael Klingler and Mr Ashraf Al-Eryani (GTZ);
- Dr Gerhard Lichtenthaler (GTZ);
- Mr Saleh Al-Dubby (Sana'a basin World Bank project);
- Dr Ismail Muharrm (Agricultural Research Extension Activity);
- Mr Ton Negenman and Mr. M. Al-Aroosi (Royal Netherlands Embassy);
- Mr Naju Abu Hatim (WorldBank);
- Mr Saleh Al-Dubby and Eng. Ali Shouaib. (Sana'a Basin WB project);
- Eng. Mutahar Zaid Mutahar (General Department of Irrigation, MAI).

Appendix 2

Factors that have triggered groundwater overdraft

In 1968 Yemen emerged from a civil war and its economy was in very bad shape. It was among the least developed countries of the World with a per capita income of about USD120 per annum in 1971. The government has successfully introduced some basic elements of modern administration starting in 1970 and because of its limited natural resources encouraged Yemenis to emigrate abroad especially to Saudi Arabia and other Gulf countries. That policy worked fairly well and workers remittances plus foreign aid and grants have increased substantially over the years. It was estimated that workers' remittances rose from only USD40 million in 1969/70 to over USD800 million in 1976/77 largely as a result of those cash inflows per capita income has more than doubled during the period 1970 - 1975 which allowed a significant increase in demand for food products and Qat. As a result of the changing market structure many farmers started to invest in irrigation wells and pumps and began shifting from growing cereals such as sorghum, barely and millet to high income crops such as fruits, vegetables and Qat. Before that time agricultural production consisted predominately of rainfed grains and only modest quantities of cash crops, fruits and vegetables were produced. The rainfed agriculture accounted for 85% of the cultivated area. Spate irrigation represented about 10% of the cultivated land. Pump and perennial irrigation area accounted for only 7.3% in 1969.

However, as a result of the changing market situation cropping patterns changed also and well irrigation started to increase in a rapid way. It became the stated policy of the government to increase the areas irrigated by spate and well irrigation. This policy was clearly stated in the government second five year plan for the period 1981-1986. The targets for irrigation were more than realised over the years for well irrigation by the increase in investments by both the private and public sectors in irrigation systems especially drilling of wells and installing of pumps. The government and the farmers unfortunately paid little attention to the overall resource limitation and excessive use of groundwater abstraction has dangerously resulted in lowering of the water tables in many parts of Yemen and salinity problems were observed in Tihama. The huge investments by the private and public sectors in irrigation equipment was not accompanied by improvement in irrigation practices in farms and according to experts more than 50% of the water pumped was wasted because of inappropriate irrigation methods.

Factors which drove groundwater overdraft over the last thirty years

The rising incomes in Yemen beginning in 1970 resulting from increased amounts of remittances plus the increase in foreign aid and grants were the main factors which caused the over exploitation of water resources in Yemen especially underground water to meet the increased demand for food products and Qat. The lack of research and extension services to help farmers in adopting modern irrigation methods was another important reason for wasting precious underground water resources. However government policies over the last thirty years were responsible for the acute scarcity and overdraft of underground water resources.

The government since 1973 embarked on an ambitious programme to increase the cultivated areas devoted to irrigation by spate and well irrigation. The government invested large amounts of money from its own financial resources and from loans and grants in rural and urban water projects to increase water supplies to meet the growing demnd for domestic purposes and for agriculture. Thousands of wells were drilled and thousands of pmps and motors were installed by the government not only for domestic purposes but also for irrigation of crops all over the country since 1973/74. In fact many of the wells which were drilled and equipped by pumps and financed by the government ended up in irrigating Qat since no control and supervision was maintained to ensure proper use of those wells and pumps.

Government policies and actions were responsible over the last thirty years for the overdraft of groundwater resources in Yemen in addition to the increased income of the farmers resulting from remittances which increased dramatically since 1973. Cropping patterns changed substantially since 1971 in favor of cash crops, fruits, vegetables and Qat. All those products depended on water from wells. There were other factors and policies which caused the over exploitation of underground water resources. In 1975 the government created the Cooperative and Agricultural Credit Bank to finance different agricultural projects. About 30% of the Agricultural Credit Bank medium term loans have been to finance investments in irrigation systems. Those loans were provided to farmers at a very low interest rates and many of those loans were never paid back to the Bank until the present time. Mechanical pumping of water from wells became popular among farmers all over the country.

In Marib and Al-Jawf regions thousand of wells were drilled and equipped with pumps to grow wheat, citrus fruits and watermelons. The Tihama region witnessed drastic change in crop patterns. Thousand of wells were drilled all-over the Tihama region to produce a wide variety of agricultural products such as bananas, papayas, tomatoes, melons and lately mangoes. Salinity problems and decreased water tables were recorded by experts all over Tihama. Agriculture continued to be the main user of water accounting for at least 90% of water consumption in the country despite the fact that scarcity of water represented serious problems for urban and rural households especially in places like Taiz, Sana'a, Amran, Hajja, Baidha and Dhala. However, the challenge for Yemen regarding water is in agriculture where the average need per capita for food needs is more than 3,500 liters per day according to estimates by UNDP. Domestic needs in Yemen are only 25 litres per capita for rural population and 50 - 60 litres for the urban population.

The declaration by the government in 1984 to ban the importation of fruits such as apples, bananas and oranges was another factor contributing to the rapid abstraction rates of underground water resources in Yemen. The ban on imports of fruits resulted in a big increase in the cultivated areas devoted to fruit production. Most of fruit products depended almost entirely on irrigation from wells. Data for the year 1990 indicated that 310 thousand hectares of the cultivated land in Yemen got their source of water from wells compared to only 37 thousand hectares in 1974 which meant that the area devoted to well irrigation has expanded 8 fold in a period of about 16 years, while the area cultivated under rainfed conditions has decreased by more than 50% between 1974 and 1999. Areas allocated to perennial and spate irrigation have not expanded much. In fact the cultivated area under perennial irrigation went down substantially because of the dryness of many streams. It is interesting to note also that the total area under cultivation went down from 1515 thousand hectares to 1133 thousand hectares indicating the wide variability of rain conditions in Yemen. Irrigated crops which earned farmers more incomes shifted the cultivated land in Yemen from producing grains which depend almost entirely on rains to fruits, vegetables, qat and other cash crops which depend on irrigation from wells, therefore, creating an acute exploitation of underground water resources in Yemen never happened in the history of Yemen whose ancient agricultural civilisation depended on rains and spare irrigation systems.

Since 1999 the water crisis in Yemen deepened and became more unmanageable as a result of inaction by the government and policies which encouraged further abstraction of water rather than conserving it. In addition to that, another development which happened in 1990 also contributed to the water crisis and the serious overdraft in Yemen. Because of the Gulf War in 1990, hundreds of thousands of Yemenis became unwelcomed in Saudi Arabia and Kuwait and returned back to Yemen. Many of those individuals began looking for investment opportunities and thousands of them invested their money on farming by drilling wells and installing pumps on their wells to produce fruits, vegetables and Qat. Production of Qat, and fruits such as oranges and mangoes expanded rapidly in many areas of the country where production of those individual products was suitable. For example, mango production expanded very rapidly over the last fifteen years. Depletion of underground water resources increased rapidly and many areas became completely dry.

Farmers in some parts of Yemen especially in Saddah, Amran, Sana'a and Radda began to deepen their wells because of the lowering of water tables. It was not surprising to have wells with depths of more than 400 meters. Some of those wells were producing water only for few hours during the day and production of many wells was reduced to about 3 to 4 litres per second. The cost of drilling of wells in areas like Amran, Sana'a, Saddah, Al-Dhala and Al-Baidha became a big constraint. Some wells with depths of 400 meters cost more than 40 thousand dollars for drilling alone. These high costs were made by individuals who owned Qat plantations or were selling water to other Qat growers in areas where water became very scare or not available at all. It is because of this situation that government statistics on irrigation began reporting cultivated areas which their irrigation water was brought by tankers and barrels, a situation which is unheard off in other countries of the World.

Finally, there is another important factor which made it easier for farmers to exploit underground water resources over the last 30 years. During all that long period the cost of diesel fuel was always cheep because of the government subsidies to the petroleum products.

The big influential farmers and others have been always successful in keeping oil prices, especially, diesel fuel very low despite efforts by different governments to keep these prices in line with changing international prices of fuel products. It is expected that this kind of policy will continue in the near future given the political situation in Yemen at the present and foreseeable future. Therefore, it is expected that the over exploitation of the underground water resources will continue until farmers deplete these resources or find it uneconomic to further deepen their wells. But with the continuing strong demand for Qat there is no reason for the farmers to discontinue producing this high value crop and other relatively high value cash crops and fruits. So Yemen will continue abstracting its valuable water resources unless the political leadership and the people of Yemen become clearly aware that this serious water crisis cannot continue unabated and real solutions must be implemented to mitigate it.

Investments by the public and private sector in drilling and irrigation equipment have been continued over the last thirty years without major effort to stop this trend and therefore, the number of wells in Yemen rose from few thousands in 1971 to more than 50 thousand wells at the present time. In fact some estimates by experts I interviewed over the last several weeks told me the number of wells in Yemen may be on the order of 60 to 70 thousand.

In the Sana'a Basin it is estimated there are more than 12 thousand wells. In the governorate of Al-Dhala more than 500 wells were drilled in recent years mainly for the production of qat. The General Authority of Rural Water drills more than 200 wells every year for domestic purposes alone. Other government agencies and ministries still continue to drill wells in many parts of the country for both domestic and agricultural purposes. The 200 to 300 rigs available in Yemen are not sitting idle. According to an owner of a drilling company who has been in the business of drilling since 1970 he told me that he did not notice any significant reduction in the number of wells being drilled in Yemen over the last few years. He also told me that drilling of wells is being done without permits from NWRA even after the passing of the Water Act in 2002. Information which was obtained from other sources also point out that the water act is not being implemented especially with regard to registration and drilling of wells.

Despite the fact that there is no reduction in the number of wells drilled every year it is important to note that because of the lowering of the water table in many areas of Yemen and the significant decrease in the production of pumped water from the wells drilled over the last decade or so the cultivated areas in some of the governorates are decreasing as a result of the decrease in irrigation water from wells. The cultivated area which depends on irrigation by wells in 2005 is 33% of the total cropped area. However, when the irrigated area by wells in 2005 is compared to the area in 1999 the area for 1999 was significantly higher by more than 41 thousand hectares or 9.4%. This is a very important development which indicates clearly that farmers are reducing the areas planted by irrigated crops because of the reduced amounts of available water in their wells.

Appendix 3

Key statements of the NWSSIP of relevance to this study

Guiding principles for Yemen's water policy

Principles of good natural resource management.

- Integrated water resource management and the basin management approach.
- Management of the resource for achieving efficiency and sustainability.

Social and economic principles

- *Priority to domestic uses, with due consideration to equity and poverty aspects.*
- *Allocative efficiency, so that water can flow to the use that pays the highest return, respecting basic domestic water needs for the poor.*
- *Water supply concerns are to be balanced by demand management measures, including the use of economic incentives to reduce the demand.*
- Enhancing national and household food security through market-driven growth rather than self-sufficiency.
- *Fiscal, agricultural and trade policies to be factored into water sector policy.*

Institutional principles

- Water sector governance and capacity building are considered a priority.
- Decentralisation, participation and user organisation are key policy. principles.
- Role of the private sector is emphasised.
- Role of the public sector in financing is clearly defined.
- Regulatory function is separated from service delivery.

NWSSIP p 16

Ultimately, the overdraft problem will have to be dealt with by a comprehensive 'package' of measures, including:

- *economic incentives, including trade and agricultural policy measures;*
- *regulatory measures, including self-regulation by the community;*
- *clear assignment of water use rights (linking them to specific uses);*
- technology packages that help farmers earn more income using less water.

NWSSIP p 19

Water resources management objectives are:

- ensure maximum possible degree of sustainability;
- *give priority to domestic needs of rural and urban populations;*
- *thereafter, maximise economic benefits through improved allocation, while mindful of equity and social norms;*
- create a realistic and holistic vision among the general population regarding water resources availability/scarcity;
- contribute to poverty alleviation by promoting efficient use and equity in water allocation, so as to enhance socio-economic development.

The government for its part assumes the following responsibilities:

- create an enabling institutional framework;
- provide information on water resources, raise awareness and create a shared water management vision among the beneficiaries regarding optimal management of the resources;
- supply water related public goods (infrastructure);
- *protect water rights, implement the water law, and create conducive macro-economic environment.*

NWSSIP p 20

The objectives for urban water supply and sanitation were set out in the Cabinet Resolution 237 of 1997, which adopted the reform programme. Those objectives remain valid:

- increase percentage of population covered with WSS services;
- financial sustainability of WSS utilities;
- separation of sector regulatory and service-provision functions;
- decentralisation;
- knowledge and skills development;
- community and private sector involvement.

NWSSIP p 23

Within the global objective of improving rural livelihoods and sectoral value added in a sustainable manner, the specific objectives for irrigation and watershed management are:

- *enhancing sustainability through water resources protection;*
- *improving farmers' income through increasing water use efficiency;*
- *enhancing supply;*
- improving institutional performance in support of farmers.

The approach
Reducing groundwater mining
Securing farmers' water rights: Recognition of farmers' use rights to water, acquired under the water law, and registration of these rights, is key to responsible management of such resources (paragraph 3.3.4). The MAI will therefore work with the MWE/NWRA to recognise and register farmers' use rights over water.

Getting incentives right: The importance of incentives and the measures proposed to correct them are described above (see paragraph 3.3.4). The MAI will support the proposed study of incentives, in light of which changes in the incentive structure will be proposed, discussed and adopted.

NWSSIP p 31

On Qat…

Qat now occupies at least half of the irrigated area in Yemen, growing at an annual rate of 9% (double the growth rate of other crops). This crop has even invaded virgin land never cultivated before, in addition to expansion in regions not known for its cultivation.

The reality is that between 1970 and 2000 the area under other crops, particularly grapes and coffee, has also expanded annually at nearly 3 and 5%, respectively. However, the area under qat expanded at a much faster rate (9% per year) because it is more profitable.

If the existing situation continues as it is, without intervention, then qat farming will in the end deplete the water in the rural areas and consequently wipe out the rural economy serious consideration should be given to allowing qat importation. Indeed, the hard-currency spent on developing qat farms in neighboring water-rich countries, which would permit qat growing and export to Yemen, will be much less than the hard-currency which Yemen currently spends on qat irrigation (subsidised diesel fuel; maintenance and depreciation of drilling rigs; cost of well casings, pumps and spare parts; well deepening and drilling) as well as the cost of pesticides for spraying qat shrubs and the cost of the medical bill for treatment of the pesticides-caused diseases (since Qat shrubs growing in a humid environment like Ethiopia will not need an intensive use of pesticides). This is in addition to the value of the water which will be saved as a result of reducing qat farming in Yemen.

NWSSIP pp 10-11

Appendix 4

Questionnaire for empirical field work

Questionnaire to get a better understanding of farmers behaviour regarding groundwater extraction on the basis of financial incentives, non-financial incentives, regulatory framework, collective action and individual and community wisdom

General information

Governorate name	…………….
District name	…………….
Village name	…………….
Level of education of the farmer	…………….
How many persons live from this farm?	…………….
Male or female farmer	male ( ) female ( )
Do you have any non-agricultural income?	yes ( ) no ( )
Farm size In ha or labnah or fadan or ghasabh	…………….
Do you rent (part of) the land? In ha or labnah or fadan or ghasabh	…………….
Do you own one or more wells?	yes ( ) no ( )
Do you sell water?	yes( ) no ( )
Do you buy water?	yes ( ) no ( )

If yes from who?	…………….
How often?	…………….

Do you get as much water as you need?	yes ( ) no ( )

If no, what would you do with extra water?

a) Apply more water to existing crops	yes ( ) no ( )
b) Change crop	yes ( ) no ( )
To which crop?	…………….
c) Expand area	yes ( ) no ( )

How deep is the water table in your well?	…………….m

Have you deepened your well over the last ten years?	yes ( ) no ( )
If yes when?	…………….

By how many meters?	…………….m

Is the quality of the water you use:	good ( )
	medium ( )
	poor ( )

Financial drivers

What is your major crop	…………….

What is your second major crop	…………….

How many labnah of your [second major crop] gives the same income level as one labnah of your [major crop]? …………….labnah

Are any of these farm expenses subsidised?

a) Pumps	yes ( ) no ( )
b) Diesel price	yes ( ) no ( )
c) Digging wells	yes ( ) no ( )
d) Improved on-farm irrigation equipment	yes ( ) no ( )
e) Conveyance system	yes ( ) no ( )

Non- financial drivers

Do you grow crops for your own consumption?	yes ( ) no ( )
If yes, how much of your land is used for these crops?	…………in ha or labnah

Did you change the cropping pattern?

Decreased crop	…………….	Why?	…………….
Increased crop	…………….	Why?	…………….

Do you intend to grow new crops or better varieties?	…………….
Why?	…………….

Regulatory framework

Which institution is responsible to give licences to dig new wells?	…………….
Are licences given for anyone who wants to dig a well?	yes ( ) no ( )
What are the conditions to get the licence?	…………….
Did anyone dig a well without a licence?	yes ( ) no ( )
Did you inform the authorities about illegal drillings?	yes ( ) no ( )

Collective action

Is there a Water User Group or Association in your village?	yes ( ) no ( )
If yes, are you a member?	yes ( ) no ( )
If yes, what are your expectations?	…………….
Did you previously discuss water problems with others?	yes ( ) no ( )

If no, why are you not a member?	…………….
If no, do you discuss water problems with other water users?	…………….

Individual and community wisdom

Do groundwater levels increase after the rains?	yes ( ) no ( )
Who owns the water?	…………….
If water is becoming scarce, is it better:	
a) To use it quickly before it is finished?	yes ( ) no ( )
b) To use it quickly before others use it?	yes ( ) no ( )
c) To use less and make it last longer?	yes ( ) no ( )
d) To agree as a group to use less water?	yes ( ) no ( )
Does scarcity becomes more dangerous in the future?	yes ( ) no ( )
If yes, why?	…………….
What action can you take as an individual?	
Put deeper well?	yes ( ) no ( )
Put new well?	yes ( ) no ( )
Change technology	yes ( ) no ( )
Change crop	yes ( ) no ( )
To which crop?	…………….
Reduce hours of pumping	yes ( ) no ( )
Reduce area irrigated	yes ( ) no ( )
Reduce the water-intensive crops	yes ( ) no ( )
Other suggestions	…………….
What action should be taken by your community:	
Limit number of wells	yes ( ) no ( )
Reduce hours of pumping	yes ( ) no ( )
Reduce area irrigated	yes ( ) no ( )
Reduce the water-intensive crops	yes ( ) no ( )
Other suggestions	…………….

What action should be taken by the government?	
None	yes ( ) no ( )
Stop new well digging	yes ( ) no ( )
Stop deepening of wells	yes ( ) no ( )
Reduce irrigated area	yes ( ) no ( )
Reduce water-intensive crops	yes ( ) no ( )
Construct dams/reservoirs	yes ( ) no ( )
Subsidise improved irrigation technology	yes ( ) no ( )
Provide alternative jobs	yes ( ) no ( )
Organise farmers for collective action	yes ( ) no ( )
Punish illegal drilling	yes ( ) no ( )
Other suggestions	……………
Do you want to use improved irrigation technology?	yes ( ) no ( )
If no, why not	……………
If yes, what will the benefit be for you?	……………

Have you received advice on saving water?	yes ( ) no ( )
If yes, on what?	……………
Will there still be water for your son/grandson?	yes ( ) no ( )
What do you see as an alternative for the future?	……………

Appendix 5

The impact of improved irrigation technology on water savings.

Reducing losses and increasing the productivity of water: does modern irrigation technology help manage the resource?

Chris Perry,[1] February 2008

This paper is in two parts. The first part, aimed at non-specialists with an interest in water resources management, is designed to better inform the long-running discussion about the impacts of improved irrigation technology (drip, sprinkler, bubbler systems). It is widely assumed that such technologies save large quantities of water and greatly increase the productivity of water. Often - but not always - such assumptions are greatly exaggerated, distorting policy recommendations and investment priorities. The second part applies these ideas to the case of Yemen - an exceptionally water-short country where improved irrigation technology is the cornerstone of donor policy.

A. Technical background[2]

Terminology

The basis for meaningful discussion and analysis in this area must be a clearly defined set of terms. Widely used but ill-defined concepts of 'efficiency' lead to misleading conclusions. In part this is because different disciplines (irrigation engineers, economists, agronomists, resource planners) infer 'benefits' that conform to their particular point of view (more precise application of water, higher value of water, higher crop yields, availability of water for alternative

[1] This paper has been produced as part of the ongoing study 'Options for Changing the Economic Incentive Structures for Groundwater Extraction in Yemen'.

[2] I am most grateful to the following internationally recognized experts for their review and comments on the arguments presented in this section: Charles Burt, (Chair, Irrigation Training and Research Centre, Cal - Poly); Richard G Allen (main author of FAO Publication 56 on Crop Water Requirements); Pasquale Steduto (who leads the ongoing FAO analysis of the relationship between crop water use and yield); and Harald Frederiksen (former Principal Water Resources Specialist in the World Bank). Every effort has been made to reflect their comments, which were uniformly supportive of the general thrust of the argument, errors remain the responsibility of the author.

uses). Some, all or none of these good things can be the outcome in the multiple scenarios in which 'improvement' takes place.

In consequence, the International Commission on Irrigation and Drainage[1] has over the last two years consulted all its National Committees, various Working Groups, and many expert individuals, and adopted terms that avoid the word 'efficiency' altogether, relying instead on the hydrological framework that simply defines component water flows. These are:

2 *Water use*: application of water to any specified purpose, comprising;
2.3 *Consumed Fraction*: Water evaporated or transpirated, comprising;
2.3.1 *Beneficial Consumed Fraction*: Water consumed for the desired Purpose*;*
2.3.2 *Non- beneficial Consumed Fraction*: Other evaporation or transpiration;
2.4 *Non- consumed Fraction:* Water not lost to the atmosphere, Comprising;
2.4.1 *Recoverable fraction*: Water that can be recovered and re-used;
2.4.2 *Non- recoverable fraction*: Water that cannot be economically Recovered.

The benefits of this framework include: identification of consumptive uses (crops transpire water - a consumptive use - while most domestic uses are non-consumptive. Low-flow showers reduce water *use* but have no effect on *consumption*); clarity in identifying how water can most effectively be saved (by reducing *non-beneficial* consumption and the *non-recoverable* fraction); and making sure that the accounts are done properly, because the sum of the component flows at each level MUST add up to the flow at next level - no more and no less.

Traditionally, 'irrigation efficiency' has been calculated as the ratio of 2.1.1, above, to 1 - a term, that can vary greatly depending on the scale of observation (Egypt is 85% 'efficient' at the national scale, but only about 40% efficient at field scale, because most field 'losses' simply return to the Nile. Because of this measured diversions from the Nile are at least 50% higher than the water available to the country - a rather confusing statistic that suggests that a further reduction in 'efficiency' could make even more water available to Egypt!).

The term 'Water Use Efficiency' is also proposed by ICID to be replaced by 'water productivity'. Although WUE is internationally defined as a productivity

[1] Efficient irrigation; inefficient communication; flawed recommendations. Perry, Chris. Irrigation and Drainage (Volume 56, Issue 4, Pages 367-378).
http://www3.interscience.wiley.com/cgi - bin/abstract/114281744/ABSTRACT.

term (output of crop per unit water applied, for example), it is one of the most misused terms in the literature.

Other terms needed for the analysis are evaporation (E) which is direct consumption of water - for example when wet soil is exposed to the atmosphere - and transpiration (T) which is the water that goes through the crop in the process of plant to growth. (ET is the combined total of evapo-transpiration which is measured - for example in lysimeter experiments. It is often difficult to precisely separate ET into its constituent components based on field measurements.)

Technology

Traditional forms of irrigation tend to apply large quantities of water relatively infrequently. For example, the climate may be such that the crop needs 5mm/day to grow. To meet this need, the farmer may supply 50mm every week. At the field level, it may be observed that large areas of soil are wetted, that some of the applied water percolates into the soil beyond the root zone, or runs off the field into drains. Additionally, if the field is not well levelled, some plants will get excessive water while others do not get enough.

This local observation suggests that crop needs could better be met by more precise delivery of the required amount of water at the right time. This is what improved irrigation technologies aim to do - providing the required amount of water to each plant with minimum runoff or percolation. Irrigation applications are typically light, frequent and directed (in the case of drip and bubbler) to the individual plant.

In 'ICID terminology', in the traditional situation described above the *water use* of 50mm would (at best, assuming even application) lead to 35mm (seven days * 5mm/day) of *beneficial consumption* leaving some 15mm is unaccounted for. To complete the accounts, we need to know whether the additional water went to *non-beneficial consumption*, to the *non-recoverable fraction*, or to the *recoverable fraction*. In general, in situations where there is an exploited, relatively shallow aquifer in the area, percolation losses are largely recoverable. In assessing this, it is important to consider water quality: if the local soil or underlying aquifer is saline, percolation water will pick up salts and may not be reusable.

Similarly runoff that goes back to a water system upstream of irrigation or other intakes will be *recoverable*, while drainage that go to the sea or a salt sink is *non-recoverable.* (Recovery will often require additional energy inputs - a real cost - but our interest here is water, not energy).

In the example cited above, a switch to improved irrigation technology would have the following typical effects:

- *water Use* (the volume of water applied) would fall-sprinkler irrigation would allow daily application of appropriate quantities of the entire cropped area; drip or bubbler would allow daily application directly to the plant this reducing the area wetted;
- careful management would reduce the *non-consumed fraction* (percolation and runoff) virtually to zero.

The primary impact of improved irrigation technology is consequently a reduction in *water use*. However the extent to which this reduction translates into *water savings* that will be available for use elsewhere depends entirely on the hydro-geological situation, which determines whether excess deliveries are *recoverable* or *non-recoverable*.

The hydro-geological context, then, is the primary determinant of the impact of improved irrigation technology in terms of water consumption.

Second-order impacts should also be considered and are not always straightforward. It is often assumed that *non-beneficial evaporation* is higher with conventional irrigation because the entire field is flooded (or relatively large basins around trees), whereas improved technology directs the water precisely to the plant with minimum extra wetting. In fact, since improved technologies involve more frequent irrigation, the smaller wetted area may be wet (and evaporating) for a longer period than with the heavier, less frequent irrigation schedule. Further, the local evaporation from wetted soil acts to increase humidity and decrease transpirative crop demand. Except for widely spaced tree crops the savings in E with drip and bubbler irrigation is small. For sprinkler, E may often be higher as the entire area is frequently wetted, and wind can divert the water to areas not intended for irrigation.[1]

It is also widely assumed that the *productivity of water* (in ICID terms, production per unit of beneficial consumption, or transpiration) is increased with improved irrigation technologies - that is, that the same quantity of crop can be produced with less water, or more crop with the same quantity of water. Here it is essential to clarify the basis of the argument. For any given crop, production (in terms of biomass) is essentially a direct function of transpiration: an increase in production will require a similar increase in transpiration - so that productivity is constant.

[1] Where these issues are important, models exist that can quantify the likely impacts of various irrigation technologies.

There are several caveats to this point: first, and importantly, improved irrigation technology often facilitates changes in cropping pattern to higher value crops. This may significantly increase productivity in USD per m^3 terms. Water consumption will increase or decrease, depending on characteristics of the new crop. Second, at very high levels of management it may be possible to manage water stress in ways that improve the productivity of water - however this is very much a second order effect and only relevant when very high yields and excellent water management are already in place. Third, improved irrigation techniques can significantly improve the effectiveness of fertiliser application (either through direct distribution - 'fertigation' - or by avoiding leaching.) Again, the extra biomass generated through these improvements will result in higher T, and more water consumption. Finally, the improved distribution of water over the field will reduce excess application in some areas (possibly a saving, depending on the situation) while increasing the supply to other areas (a certain increase in consumptive use).

Salt management

Reference has already been made to salt in the context of whether percolation is recoverable or not. Improved irrigation technologies also have more general implications for salt management, especially because good irrigation management is needed in areas of water scarcity and climatic aridity. Here, the need to manage salt in the soil profile is of particular importance. Traditional irrigation systems that apply infrequent heavy irrigation usually ensure downward movement of water (and salt). Frequent light irrigations do not achieve this and salt management, so that occasional heavy irrigations may be required.

Local incentives, basin impacts

From the perspective of a farmer who has either a limited entitlement to surface water or limited ability to pump from an aquifer, the incentive to improve irrigation technology is clear. He or she will be able to increase the *beneficial consumed fraction* - which is the water that his crops consume - and hence increase production and income. For every unit of water available to his farm, he can grow more crops. Total *consumption* of water at the farm level will increase while *water use* (diversion or abstraction) remains constant.

From the basin (or aquifer) perspective, these farm-level benefits are unlikely to be neutral in water terms. Only if all the excess water the farmer was applying initially was *non-recoverable* is the usable water balance unchanged. In the more common case where a significant part of the excess water was *recoverable*, then from the basin (or aquifer) perspective, things will now be worse because consumption has increased. Further, as a result of the increased value of *applied water*, the farmer will be able to compete more vigorously for the smaller remaining pool.

B. Hydrogeology of Yemen's Irrigated Areas, Improved Irrigation Technology and Implications for 'Water Saving'

Yemen's Primary Source of Water-Aquifers

It is widely observed and accepted that most of the groundwater-irrigated areas of Yemen are over drafted. In some areas, the rate of overdraft is such that the water table is falling by several meters each year; elsewhere the rate of fall is lower but still persistent.

Overdraft occurs when the volume of water abstracted exceeds recharge. The *volume of water abstracted* is equal to the total volume pumped, and the *recharge* is equal to the water that reaches the aquifer as a result of infiltration from rainfall and other sources - often including excess application of irrigation water.

When the quantity of water available at the surface exceeds the capacity of the top layer of the soil to store the water, the excess either runs off, forming a stream, or infiltrates into the lower soil profile. The distribution of the excess moisture between non-beneficial consumption, runoff and infiltration depends upon the quantity of excess water (very light rainfall will tend to be temporarily stored near the soil surface, and evaporate during subsequent dry days) and the nature of the soil. Obviously, infiltration is a source of local recharge, and when the underlying materials are filled to capacity, an aquifer is formed.

The soil in the aquifer is said to be *saturated*, whereas the soil above the aquifer, through which the infiltration must pass to reach the aquifer is *unsaturated*. This distinction is critically important, and may be understood as follows: if a hole is dug vertically into the ground, then while the soil above the aquifer may be moist, that moisture is 'held' in the soil. As soon as the hole extends below into aquifer, water will flow out of the *saturated* soil and fill the hole up to the level of the top of the aquifer. Wells must therefore penetrate into the saturated zone - the aquifer - in order to be productive.

Whether infiltration reaches the aquifer depends further upon a number of parameters, including:

- nature of the soil-permeable soils allow water to pass readily; impermeable soils allow little or no water to pass;
- variations in soil type with depth;

- if permeable layer is underlain by an impermeable layer, the upper layer forms an aquifer as excess moisture infiltrates and accumulates over time;
- if a permeable layer is underlain by an impermeable layer that is further underlain by a permeable layer, then the lower permeable layer may be an aquifer but cannot be replenished by vertical infiltration from the surface because of the impermeable layer (this is a *confined* aquifer);
- the depth from the soil surface to the aquifer. If the unsaturated zone is deep and relatively impermeable, then recharge may take many years to reach the aquifer.

This brief overview of the nature of aquifers and their recharge - which covers most of the scenarios found in Yemen - already indicates that the patterns of flow induced by excess irrigation are complex and must be locally understood. In particular, with reference to the analytical framework adopted by ICID, it is critical to distinguish which excess irrigation deliveries that are *recoverable* and *non-recoverable*, and what proportion of excess deliveries goes to *non-beneficial consumption* (basically evaporation).

Yemen's Primary Use of Water-Irrigation

In parallel with the observation that Yemen's aquifers are over drafted, it is also observed that irrigation practices are crude and wasteful - large quantities of water are diverted through unlined channels and applied with very little control to the fields. The quantity applied is generally far greater than required on the basis of scientific computation of crop needs. The implication of this observation is that improved irrigation technologies (piped supplies, precise application) and management (more frequent application of limited volumes of water) will save large amounts of water and reduce the pressure on the aquifers.[1]

The logic of this argument is simple: if a plant needs X quantity of water, but in order to provide this quantity it is necessary to pump 3X because water leaks from field channels and excessive water is applied to the field, then the 'demand' on the aquifer is three times the crop's need. If pipes and scientific scheduling and improved irrigation technology can reduce the pumping requirement to 1.5X, then the demand on the aquifer is halved. (In ICID terminology, *water use* has halved.)

[1] An economist would wonder why farmers (who generally teach us more than we teach them) would pay very high rates for very scarce water are then silly enough to waste it through 'inefficient' irrigation. Further studies may be illuminating.

(Experience suggests that it is worth reiterating at this point that this analysis is about *water*, not *power*. Any reduction in pumping as a result of improved irrigation technologies will save power, an unambiguous benefit. The topic here, however, is water.)

Improved Irrigation Technology - Scenario 1

The following tables and charts now explore the likely benefits (in water terms, not power terms) of improved irrigation technology that reduces *water use* in order to meet a defined level of *beneficial consumption* in a situation where excess irrigation applications are *non-recoverable* - in other words, the areas best suited to improved irrigation technology.

It is assumed, based on estimates in projects documents and the donors' *Joint Vision* statement (2007), that losses can be reduced from 65% to 40%. It is further assumed that once the technology is installed, it is fully used, that farmers immediately reduce deliveries to fields, farmers do not expand their irrigated area, and that maintenance is adequate to keep the new technology fully functional. This may be termed the optimistic scenario.

The analysis is presented in terms of a single unit of pumping (*water use*). This will result in 0.35 units of *beneficial use* if losses are 65%. With the improved irrigation technology and losses reduced to 40%, the same level of *beneficial use* will require only 0.58 units of pumping (0.58 * 0.6 = 0.35).

These basic data are summarised in table E1. Note that *Water Use* is reduced while *Beneficial Use* is maintained constant, which is the plan for these project areas.

Table E1	**Losses, ET and Water Use**	
	Now	**Potential**
Losses %	65	40
Beneficial Use	0.35	0.35
Water Use (pumping	1.00	0.58

Table E2 traces the impact of investment programmes introducing the improved technology, on the basis of a 10-year programme (i.e. it will take ten years to cover the entire irrigated area with the new technology), and a slower, twenty year investment programme.

These data are most easily understood by first looking at the year when implementation is complete (year 11 for the 10-year programme, year 21 for the 20-year programme) and noting that *water use* is now at the reduced level of

0.58 compared to 1 in year 1. Interim years are simply linear interpolations between these two points, reflecting steady, continuous project implementation (the Sana'a Basin water Management Project appears to be based on a twenty years programme for full coverage.

Table E2	**Annual Abstraction for 10 and 20 year investment programmes**	
Year	**10 year**	**20 year**
1	1.00	1.00
2	0.96	0.98
3	0.92	0.96
4	0.88	0.94
5	0.83	0.92
6	0.79	0.90
7	0.75	0.88
8	0.71	0.85
9	0.67	0.83
10	0.63	0.81
11	0.58	0.79
12	0.58	0.77
13	0.58	0.75
14	0.58	0.73
15	0.58	0.71
16	0.58	0.69
17	0.58	0.67
18	0.58	0.65
19	0.58	0.63
20	0.58	0.60
21	0.58	0.58
22	0.58	0.58
23	0.58	0.58
24	0.58	0.58
25	0.58	0.58

Figure E1 plots the cumulative abstraction that results from three scenarios: first, if no changes are made, then abstraction will continue at 1 unit per year (assuming no expansion of irrigated area); if the 10 year investment programme is followed, cumulative abstractions will (for example) in year 3 be equal to:

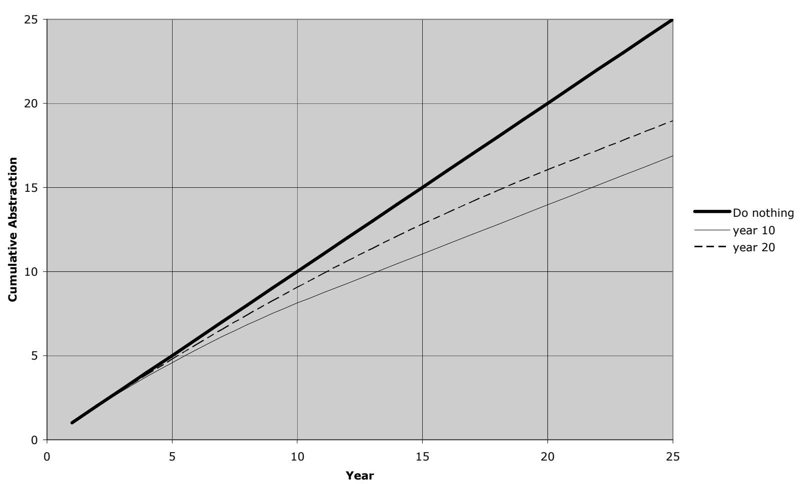
$$1+0.96+0.92 = 2.88$$

The cumulative abstraction for the 20-year programme is derived similarly. The graph show a progressive divergence between cumulative abstraction between the 'Do nothing' scenario and the 10- and 20-year investment programmes, with the 10-year programme producing larger, quicker divergence.

Estimates of the period of time that the Sana'a aquifer can support existing levels of pumping are uncertain, but 10 years is sometimes suggested. An interesting observation from this simple, yet rather optimistic analysis is that cumulative pumping for the 20 year investment programme will reach the 10 year 'Do nothing' level around year 11, and even the 10 year investment programme only extends the aquifer life by about three years.

Additional conclusions are equally disturbing: The 'ten years remaining' scenario is an average. Some areas are already close to exhaustion while other areas still have relatively plentiful supplies remaining. It is only worth investing in the areas where water is still available, and those who are most at risk will benefit little from investments of several thousands of dollars per hectare.

Figure E1 Cumulative abstraction over time



Clearly this analysis is simplistic, though the conclusions are rather similar to the recent JICA report[1] which anticipates depletion of Sana'a's aquifers within 15 years even with very substantial improvements in 'irrigation efficiency'.

Additional benefits that have been ignored include the fact that returns per cubic meter of water consumed by the crop can be higher with better irrigation technologies if cropping patterns change or crop husbandry improves significantly; labour is saved, increasing farmer profitability (at the expense of income to labourers).

However, against these positive factors, it is assumed that everything goes strictly according to plan; that all the farmers immediately achieve the full benefits of the investments; and most importantly that farmers do not increase their irrigated areas or sell water to others (despite the fact that every hour of pumping with the new system will allow irrigation of about 60% more area).

Improved Irrigation Technology - Scenario 2

The analysis so far is based on the most beneficial scenario for improved irrigation technology, where ALL uses other than *beneficial consumption* are non-recoverable losses. The impact on aquifer life is shown to be marginal.

However, where there is vertical recharge to an aquifer that is usable, the volume of water actually 'saved' will be much, much less than implied by the crude ratio of *water use* before and after 'improvement'. Power will be saved; degradation of water quality may be avoided; and minor savings in non-beneficial consumption may be achieved. Production may well increase - but this will generally be because crop transpiration, a *consumptive* use of water, has increased. Overall the water balance may be worsened.

Most importantly, however, the profitability of water use will increase dramatically and the farmer's incentive to pump more water, and ability to afford to pump from deeper, will be significantly increased. The already near impossible task of controlling pumping will be made more difficult.

[1] Study for the water resources management and rural water supply improvement in the republic of Yemen water resources management action plan for Sana'a basin, Earth System Science Co and Japan Techno, September 2007.

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