Water Resources of Abu Dhabi Emirate, United Arab Emirates

هيئة البيئة-أبوظبي
Environment Agency-ABU DHABI

مبادرة ابوظبي
العالمية للبيانات البيئية
Abu Dhabi Global
Environmental Data Initiative

Water Resources

of Abu Dhabi Emirate, United Arab Emirates

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- البيانات
- الأدوات والأساليب
- التوعية
- بناء القدرات
- السياسة

الأوراق القطاعية

خلال السنوات الماضية قامت مختلف القطاعات المعنية بشؤون البيئة بتجميع كم من المعلومات المتنوعة بعدة صور تصف ما هو معروف عن البيئة في إمارة أبوظبي ودولة الإمارات العربية المتحدة والخليج العربي. خلال المرحلة الأولى لمبادرة أبوظبي العالمية للبيانات البيئية، تم تنظيم سلسلة من ورش العمل في عام ٢٠٠٥ لجمع المعنيين من هذه المنظمات ، لتحديد القطاعات ذات الصلة، ووضع إطار العمل لكل ورقة قطاعية، ومعالجة الاحتياجات الاجتماعية والاقتصادية والبيئية الرئيسية في إطار كل القضايا المتعلقة في القطاع . من خلال هذا الورش، تم إعداد ثماني ورقات لقطاعية ونشرها:

- التلوث وإدارة النفايات
- القوانين والسياسات البيئية
- الموارد المائية
- الجغرافيا الطبيعية لإمارة أبوظبي
- البيئة البحرية والساحلية
- التراث التاريخي والأثري والثقافي
- التطور الاقتصادي والسكاني
- التعليم والتوعية البيئية

وتم إعداد قطاع إضافي كجزء من البرنامج الأصلي، ومع ذلك، وسيتم نشرها للمرة الأولى كجزء من المرحلة الثانية:

- البيئات البرية وموارد الأرض

و لأن الأوراق القطاعية هي مجموعة من أفضل المعارف المتاحة المتعلقة بالقطاعات البيئية والاجتماعية-الاقتصادية الرئيسية وتمثل أساس كافة المخرجات التي سيتم إصدارها لاحقا كجزء من المرحلة الثانية للمبادرة، تم مراجعة الأوراق القطاعية الأصلية. وتم خلال ورشة العمل الدولية التي عقدت في عام ٢٠٠٧ تحديد ما يلي:

- بشكل عام، تم إعداد الأوراق القطاعية الأصلية بشكل جديد قدم فيها مجموعة قيمة من المعلومات
- لم تصل مشاركة الشركاء والجهات المعنيين إلى الحد المخطط له
- تم أعداد الأوراق القطاعية بدون دعم كافي من الهيئة أو الشركاء والجهات المعنيين، وبالتالي، كان على مؤلف الورقة القطاعية تحمل عبء إعداد ورقة هذا القطاع في وقت زمني محدود نوعا ما
- في بعض الحالات كانت البيانات المستخدمة قديمة نسبيا
- لم يتم إضفاء الطابع المؤسسي على عملية جمع البيانات وتبادلها

تهدف مراجعة المبادرة في إطار المرحلة الثانية إلى معالجة هذه الثغرات، فضلا عن غيرها من الثغرات التي تم تحديدها كجزء من الأوراق الأصلية. ولأن تنفيذ مهمة فرق العمل تم كجزء من المرحلة الثانية من البرنامج، فقد تم تقديم الدعم على جميع المستويات لمساعدة موظفي هيئة البيئة – أبوظبي والشركاء والجهات المعنية على معالجة وتحديد الثغرات، وجمع البيانات وإجراء التحليلات وتطوير مخرجات البيانات المكانية، وبناء العلاقات مع الشركاء والجهات المعنيين، وفي نهاية المطاف ، إعداد الورقة القطاعية وتنقيحها.

وتشكل الأوراق القطاعية مصدرا قيما للمعلومات البيئية والاجتماعية والاقتصادية لأبوظبي وتم استخدمها لمراجعة وتنقيح تقرير حالة البيئة لإمارة أبوظبي فضلا عن إعداد الأطلس البيئي لأبوظبي (النسختين المطبوعة والتفاعلية).

ولمزيد من المعلومات حول المبادرة أو للوصول لنسخة الكترونية من الأوراق القطاعية، يرجى زيارة الموقع الإلكتروني في www.agedi.ae.

ما هي مبادرة أبوظبي العالمية للبيانات البيئية ؟

تم إطلاق مبادرة أبوظبي العالمية للبيانات البيئية في الثاني من سبتمبر ٢٠٠٢ خلال مؤتمر القمة العالمي للتنمية المستدامة الذي عقد في مدينة جوهانسبرغ بجنوب إفريقيا من قِبل دولة الإمارات العربية المتحدة، كمبادرة شراكة من الصنف الثاني، لتكون أداة مبتكرة لِتنفيذ الأحكام المتعلقة بالبيئة والواردة في الفصل ٤٠ من جدول أعمال القرن ٢١ وفي الأهداف الإنمائية للألفية.

وفي أوائل عام ٢٠٠٧ ، نظمت بأبوظبي ورشة عمل دولية لاستعراض الانجازات التي حققها برنامج المبادرة ووضع خطة إستراتيجية لمدة خمس سنوات. وعلى هذا النحو، بدأت المرحلة الثانية من المبادرة في عام ٢٠٠٨ بناءا على ما تم انجازه في المرحلة الأولى، في حين تم معالجة الفجوات التي تم تحديها من خلال المعلومات التي وفرتها الجهات المعنية خلال ورشة العمل.

ولا تزال الرؤيا التي تعمل وفقها المبادرة في المرحلة الثانية هي "وضع وتنفيذ نماذج عملية يمكن تكرارها وتكييفها من أجل إنشاء هيكل أساسي للبيانات البيئية المكانية عالية الجودة، للمساهمة في توفير القاعدة العلمية لاتخاذ القرارات". وسيتم في المرحلة الثانية استخدم الدروس المستفادة لتحقيق نجاح أفضل في تنفيذ المبادرة في مرحلته الثانية.

وسيركز البرنامج الحالي على وضع سلسلة من المخرجات التي تتناول قضايا محددة في حين يتم تحقيق نتائج مؤسسية معينة، بما في ذلك:

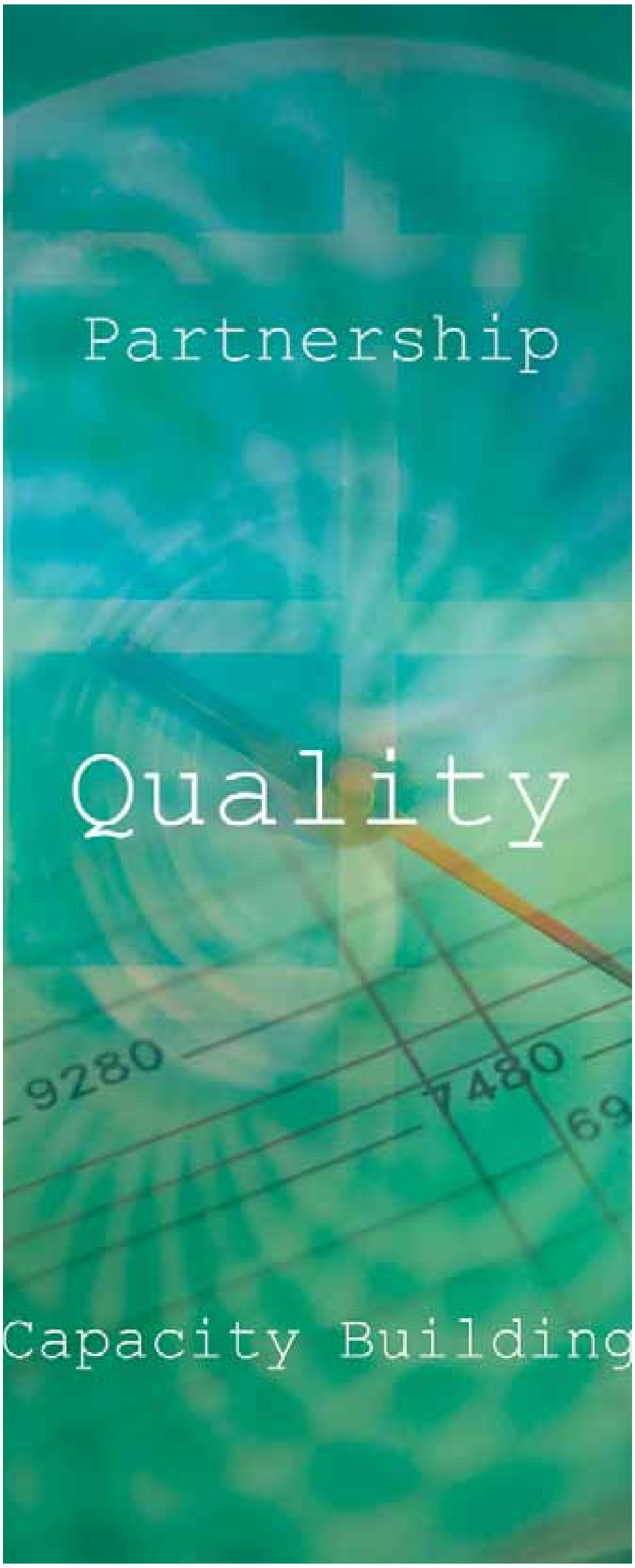
١. توفير بيانات بيئية أكثر جودة
٢. تحديد الثغرات في البيانات والأولويات
٣. تنسيق أقوي وشراكات لتبادل البيانات
٤. أساليب وأدوات أفضل للمعلومات
٥. ربط الإستراتيجية والتشغيل بشكل أفضل
٦. تحسين البنية التحتية البشرية والتقنية
٧. مؤسسة أقوي بشكل عام

والمخرجات التي تم تحديدها في إطار عملية التنمية هي أمور مترابطة ومتعاقبة مع المخرجات الأولية لدعم المعلومات والتفاهمات التي تصب في الأنشطة اللاحقة. وهي تشمل ما يلي :

- مراجعة الأوراق القطاعية وقاعدة المعرفة
- مراجعة وتنقيح تقرير حالة البيئة
- الأطلس البيئي التفاعلي
- تعزيز بوابة البيانات المكانية
- تحسين الموقع الالكتروني
- مؤشر الأداء الحكومي لابوظبي
- برامج وضع الإستراتيجية

ولضمان تحقيق نتائج ايجابية وتوفير الموارد التقنية الكافية للقيام بتطوير المخرجات، تم إنشاء مجموعة من فرق العمل بهدف تجميع الموارد لدعم فرق كل مخرج من المخرجات المبادرة. وتشمل هذه ما يلي :

What is AGEDI ?



The Abu Dhabi Global Environmental Data Initiative (AGEDI) program was fashioned around the United Nations World Summit for Sustainable Development (WSSD) Type II Partnership in 2002 as a tool to support the environmental provisions of Chapter 40 of Agenda 21 and the Millennium Development Goals.

In early 2007, an international workshop was conducted in Abu Dhabi to review the accomplishments of the AGEDI program and develop the next five year strategic plan. As such, AGEDI Phase II began in 2008 building off the accomplishments of the initial phase, while addressing gaps identified through stakeholder input during the workshop.

The vision of AGEDI Phase II remains to be a “replaceable, networked, adaptive and working model for the development and use of high quality spatial environmental data by all users within the Emirate of Abu Dhabi that will support sustainable decision and policy making.” Phase II will use lessons learned to better guide the successful implementation of AGEDI in its second phase.

The focus of the current program is to develop a series of interrelated products that address specific issues while achieving certain institutional outcomes, including:

1. Better current and quality environmental data
2. Identification of data gaps and priorities
3. Stronger coordination and data sharing partnerships
4. Better information methods and tools
5. Better links between strategy and operation
6. Improved human and technical infrastructure
7. Stronger organization overall

The specific products under development are interdependent and sequential, with early products yielding information and understandings that feed into subsequent activities. These include the following:

- Sector Paper Review and Knowledgebase
- SoE Review and Refinement
- Environmental Atlas
- Interactive Environmental Atlas
- Geospatial Portal Enhancement
- Website Refinement
- EPI for Abu Dhabi
- Programs Alignment Strategy

To ensure positive outcomes and adequate technical resources for carrying out the product development, a series of task forces were established as pooled resources to support each product team. These include:

- Data
- Tools and Methods
- Outreach
- Capacity Building
- Policy

Sector Papers

Over the years, different organizations compiled a variety of information in many forms that describe what is known about Abu Dhabi, the UAE and the Arabian Gulf Region. Through the initial AGEDI phase, a series of workshops were developed in 2005 to bring together stakeholders from all these organizations, identify the sectors that were relevant, design a framework for each Sector Paper, and address the key environmental and socioeconomic issues relevant under each sector. Through this effort, eight Sector Papers were completed and published:

- Waste Management and Pollution
- Environmental Policy and Regulation
- Water Resources
- Physical Geography
- Marine and Coastal Environment
- Paleontological and Archaeological Resources
- Population, Development and Economy
- Environmental Education and Awareness

One additional sector was scoped as part of the original program, however, will be published for its first time as part of AGEDI Phase II:

- Terrestrial Environment

Because the Sector Papers are a collection of the best available knowledge pertaining to key environmental and socioeconomic sectors and serve as the basis for all subsequent products to be developed as part of AGEDI Phase II, a review of the original Sector Papers was conducted. Already known through the international workshop held in 2007 was:

- Overall, the original papers were done well and provided a wealth of information
- Stakeholder participation did not reach the level originally intended
- Sector Papers were developed without much agency or stakeholder support, and therefore, became the burden of the Sector Paper authors under a fairly limited timeframe
- Data used was outdated in some cases
- Data collection and sharing did not get institutionalized

The review under AGEDI Phase II sought to address these gaps, as well as the other gaps already identified as part of the original papers. Because the Task Forces were implemented as part of the Phase II program, support was provided at all levels to assist EAD staff and stakeholders in addressing and identifying gaps, collecting data, conducting analyses and developing spatial products, building stakeholder relationships, and ultimately, developing a refined Sector Paper.

The Sector Papers are a source of valuable environmental and socioeconomic information for Abu Dhabi and were used to review and refine the State of the Environment (SoE) report for Abu Dhabi as well as develop the Abu Dhabi Environmental Atlas (both hard-copy and interactive versions).

For more information and online versions

For more information about AGEDI or to access online versions of the Sector Papers, please visit the AGEDI website at www.agedi.ae

توفر حوالي 4%. ويُقدر مخزون المياه الجوفية الحالي بحوالي 640 كيلو متر مكعب ولكن اقل من 3% من هذه الكمية هي مياه عذبة. وبالنظر إلي معدلات الضخ الحالية، فإن المياه الجوفية، بمختلف أنواعها سوف تنضب من الإمارة في غضون 50 عاماً. وتواجد الكثير من حقول الآبار التي يتم استخراج المياه الجوفية منها سواءً كانت عذبة أو مالحة قد تسبب في حدوث انخفاض شديد في مناسيب المياه الجوفية في بعض المناطق وتدهور كبير في نوعية هذه المياه. وقد ركزت السياسات المائية بالإمارة على إمدادات المياه أكثر من التركيز على إدارة الطلب الفعلي لهذه المياه وذلك من خلال إنشاء العديد من محطات التحلية وحقول المياه العالية التكلفة. وقد أدت هذه السياسة إلى الوصول إلى المعدلات الحالية المرتفعة جداً في استهلاك المياه للشخص الواحد بالإمارة (550 لتر للشخص في اليوم) وهذا المعدل يعتبر أكثر من الضعف لمثيله في الدول الأوروبية والتي تملك مصادر مائية أكثر بكثير من المصادر المتوفرة بالإمارة.

وتستحوذ مياه الري للمزارع والغابات والحدائق ومشاريع تجميل الطرق على حوالي 75 % من الاستخدام الكلي للمياه في الإمارة وفقاً لإحصائيات عام 2006، بينما يستخدم الجزء الباقي للأغراض المنزلية والصناعية والتجارية. وتعتمد المزارع والغابات بشكل رئيسي على المياه الجوفية غير أن هناك بعض المزارع التي يتم استخدام مياه التحلية في ريها. أما الحدائق والمتنزهات والمسطحات الخضراء فإنه يتم استخدام مياه الصرف الصحي المعالجة أو مياه التحلية.

ونتيجة تدهور نوعية المياه بالخزانات الجوفية فقد تم الاستغناء عن حقول مياه الشرب في المنطقة الغربية ، وبعد إغلاق معظم هذه الحقول يبقى فقط 16 حقلاً منتجاً في المناطق الشرقية والتي تساهم فقط بما مقداره 4% من الاستهلاك الفعلي لمياه الشرب. ويوجد بالإمارة نحو 25000 مزرعة خاصة تستهلك ما مقداره 1741 مليون متر مكعب من المياه في العام، والتي تكون في غالبيتها مياه جوفية متندية النوعية. وقد نتج عن ذلك الإفراط في استخدام المياه لمحاولة تحسين الإنتاج الزراعي مما أدى بدوره إلي جفاف العديد من الآبار. كما أدى الإفراط في استخدام الأسمدة أو استخدامها بشكل غير الصحيح إلى تلوث المياه الجوفية بأملاح النترات ولم تظهر التحليلات التي أجريت حديثاً على عينات مياه جوفية ضمن مشروع التحليل الكيميائي للمياه الجوفية وجود دلائل على تلوث هذه المياه بالمبيدات الحشرية. وتستهلك الغابات التي تبلغ مساحتها حوالي 305243 هكتار ما يقرب من 362 مليون متر مكعب من المياه الجوفية القليلة الملوحة إلى مالحة في العام 2006. وقد أدت هذه النوعية المستخرجة من المياه اللازمة لري حوالي 63 مليون شجرة إلى العديد من الصعوبات التشغيلية. وعموماً، فإن الصعوبات التشغيلية الناتجة عن تدهور نوعية المياه ونضوبها هي عقبات شائعة في القطاعات البلدية والزراعية وقطاع الغابات، وفي القطاعين الأخيرين لا توجد سياسة متبعة لإدارة مصادر المياه بالمفهوم المتعارف عليه.

في الماضي، تسبب عدم وجود لوائح وتنظيمات لاستخدام مصادر المياه إلى الوضعية الحالية المتدهورة لهذه المصادر، ونظراً لعدم وجود هيئة واحدة مخولة لإدارة مصادر المياه، فقد كانت عمليات استخدام وتطوير هذه المصادر غير منظمة بشكل عام ، وقد أدى هذا الوضع بالإضافة إلى تكرار الجهود إلى إهدار لهذه المصادر. وقد أدت التطورات الأخيرة المتمثلة في إسناد كافة المسئوليات لإدارة وتطوير مصادر المياه في الإمارة إلى هيئة مخولة واحدة لإيجاد فرصة لتطوير إدارة متكاملة لمصادر المياه مما يبشر بنظرة لمستقبلية أكثر تفاؤلاً.

وفي عام 2005 تم إسناد كافة المهام المتعلقة بإدارة المياه الجوفية بالإمارة إلى هيئة البيئة- أبو ظبي التي تم تشكيلها حديثاً. وخلال العامين 2005 و 2006 تم الشروع في العديد من المشاريع التي تركز على الأنشطة التالية والتي تعتبر من الأنشطة الأساسية للإدارة المتكاملة لمصادر المياه بالإمارة:

- حماية وترشيد ومراقبة مصادر المياه.
- التخطيط ووضع السياسات والتشريعات اللازمة لتنظيم استخدامات المياه.
- تجميع البيانات حول المياه
- استكشاف وتقييم مصادر المياه الجوفية.
- بناء المهارات اللازمة للتعامل مع مصادر المياه وتطوير المؤسسات
- التعاون المحلي والإقليمي والدولي بما يعزز الإدارة الناجحة لمصادر المياه.
- إدارة مصادر المياه وتوفير مخزون استراتيجي يمكن استخدامه في حالات الطوارئ.
- وضع الخطة الأساسية لمصادر المياه بالإمارة.
- وضع سياسة إدارة الموارد المائية والتي شملت وضع أول دليل استرشادي لتنفيذ شبكات المياه والصرف الصحي وكذلك دراسة فصل المياه الرمادية عن المياه السوداء لتقليل تكلفة المعالجة.
- وضع الخطة الاستراتيجية لزيادة استخدام مياه الصرف الصحي المعالج في الغابات والمسطحات الخضراء.
- تطوير طرق ري حديثة مثل الري تحت السطحي والري بإماهة الجذور.
- تطوير طريقة لتحلية المياه الجوفية عالية الملوحة باستخدام الطاقة الشمسية بالاعتماد على تقنية التبخير.

وكخطوة رئيسة تجاه التحكم في مصادر المياه الجوفية، تم إقرار قانون تنظيم حفر الآبار الجوفية رقم (6م2006) في مارس عام 2006. وفي نهاية عام 2005 قامت الهيئة بعمل شبكة لمراقبة المياه الجوفية وفي إبريل عام 2006 تم البدء في تطوير قاعدة بيانات شاملة لمصادر المياه بالإمارة. كما تم في عام 2007 سد بعض الفجوات في شبكة المراقبة وإضافة بعض الآبار الجديدة.

ويعتبر إنتاج وتوزيع مياه الشرب من ضمن مهام هيئة مياه وكهرباء أبو ظبي، والتي أنيطت إليها حديثاً مسئولية إدارة وتخصيص معالجة مياه الصرف الصحي وذلك بعد النجاح الذي حققته الهيئة في خصخصة مياه الشرب. وتتبع هيئة مياه وكهرباء أبو ظبي – إلى حدٍ كبير- التوسع في برنامج التحلية حيث وفرت من خلال هذا البرنامج القدرة الإنتاجية الكافية لمواجهة الطلب المتزايد على المياه في القطاع البلدي. ويسعى مركز الأبحاث التابع للهيئة إلى مواكبة التطور في تكنولوجيا التحلية وبفضل ذلك أصبحت دولة الإمارات العربية المتحدة رائدة عالمياً في تكنولوجيا التحلية وتطبيقاتها. وبالنسبة لقطاع المياه في الهيئة فإنه يعتبر منظم تنظيماً دقيقاً وذلك بعد إنشاء مكتب التنظيم والإشراف منذ حوالي سبع سنوات.

ويتناول هذا التقرير جميع المواضيع والتحديات المتعلقة بالمياه في إمارة أبوظبي وسوف يتم استخدام نتائجه كقاعدة لتطوير مؤشرات للمشاكل التي تعاني منها المياه في الإمارة وذلك لتضمينها وتحليلها في تحديث تقرير "حالة البيئة" في إمارة أبو ظبي الذي يتم إعداده حالياً.

مصادر المياه في إمارة أبوظبي، دولة الإمارات العربية المتحدة

ملخص تنفيذي

د. محمد عبد الحميد داود

يصل تعداد سكان إمارة أبوظبي إلي حوالي مليون وثلاثمائة ألف نسمة (حسب تعداد 2006) وتقع في حزام المناطق الجافة حيث يبلغ معدل هطول الأمطار السنوي إلي اقل من 100 مليمتر مع نسبة بخر عالية (تتراوح من 2 إلى 3 أمتار في العام) مع انعدام مصادر المياه السطحية التي يمكن الاعتماد عليها ومع ذلك فإن الإمارة تعتبر من أعلى المناطق استهلاكا للمياه في القطاع السكاني على المستوى العالمي وبالرغم من أنه يتم استخدام جزء من هذه المياه في ري الحدائق والمسطحات الخضراء نظراً لعدم وجود مصدر ري تكميلي إلا أنه يجب الإهتمام بترشيد استهلاك المياه والمحافظة عليها. وبالإضافة إلى ذلك فإن مصدر التغذية الأساسي هو بالتدفق تحت السطحي عبر حدودها مع دول الجوار الجغرافي مثل سلطة عمان والمملكة العربية السعودية بينما تعتبر تغذية الخزانات نتيجة الأمطار شبة منعدمة. ويصل طول حدودها مع المملكة العربية السعودية إلى 350 كيلو متر ومع سلطنة عمان إلى حوالي 280 كيلو متر.

ويرجع استخدام وتنمية مصادر المياه بالإمارة إلى العصر الحجري الذي يعود إلى 3000 سنة قبل الميلاد ثم إلى العصر الحديدي مروراً بالعصر الإسلامي وإلى ما قبل عصر البترول ومن ثم إلى وقتنا الحالي. وعبر العصور التاريخية المختلفة، تمت المحافظة على مصادر المياه من خلال استغلال المياه الجوفية التي تستخرج من الآبار الضحلة المحفورة يدوياً واستخدام الأفلاج التقليدية وكذلك استخدام أساليب الزراعة المطرية. ولكن تغير هذا النمط بعد أن شهدت البلاد خلال الثلاثة عقود الماضية طفرة اقتصادية هائلة ترتب عليها زيادة كبيرة في عدد السكان وتنمية كبيرة في القطاع الزراعي والتوسع في إنشاء العديد من الغابات والمسطحات الخضراء والحدائق العامة والمنشآت الترفيهية مما أدى إلى زيادة كبيرة في الطلب على المصادر المائية الشحيحة. وقد أدى ذلك إلى ضغط كبير على الخزانات الجوفية مما تسبب في انخفاض مناسيب المياه الجوفية بها وتدهور نوعيتها وزيادة ملوحتها. وقد أدى الانخفاض في مناسيب المياه الجوفية في كثير من المناطق بالإمارة إلى جفاف الكثير من الآبار الضحلة وكذلك انعدام مصدر المياه الجوفية التي تغذي الأفلاج. كما أدى التدهور في نوعيتها إلي آثار سلبية نتيجة تراكم الأملاح على سطح اتربة وعلى نظم الري بالتنقيط مما قلل من العمر الزمني لنظم الري والآبار والمضخات والحاجة إلي إعادة تأهيلها وضخ استثمارات كبيرة في القطاع الزراعي. كما أدى ذلك إلي عدم الاعتماد على حقول الآبار كمصدر لمياه الشرب. وقد ترتب على هذه المضاعفات زيادة الاعتماد على مصادر المياه الغير تقليدية مثل المياه المحلاة وإعادة استخدام مياه الصرف الصحي المعالجة، وكذلك إلى استخدام أساليب جديدة لتوفير المياه مثل إقامة السدود وآبار التغذية واستغلال المياه الجوفية المهدرة بالإضافة إلى استيراد المياه من الإمارات الأخرى. ولكون المياه المستخدمة في الوقت الحالي تبلغ حوالي 26 ضعفاً بالنسبة لمياه التغذية الكلية فإن الحاجة ماسة إلى تفعيل إدارة متكاملة لمصادر المياه بهدف الوصول إلى تنمية مستدامة لهذه المصادر.
ويمكن تقسيم مصادر المياه في الإمارة إلى:

- مصادر تقليدية: الأمطار والينابيع والأفلاج والعيون، بالإضافة إلى المياه الجوفية.
- المصادر غير التقليدية: مياه التحلية ومياه الصرف الصحي المعالجة.

تتواجد المياه الجوفية في الإمارة في التكوينات الصخرية المتماسكة والغير متماسكة التي تشكل الخزانات الجوفية السطحية والعميقة والتي تسهم في توفير حوالي 79% من الطلب الكلي على المياه، يلي ذلك محطات التحلية والتي توفر حوالي 17% ثم مياه الصرف الصحي المعالجة التي

WATER RESOURCES IN ABU DHABI EMIRATE

EXECUTIVE SUMMARY

Dr. Mohamed A. Dawoud

The Emirate of Abu Dhabi has a population of about 1.3 million (2006), an arid/hyper arid climate with less than 100mm/yr rainfall, a low groundwater recharge rate (<4 % of total annual water used) and no reliable, perennial surface water resources and yet, currently, one of the highest per capita water consumptions in the world. Furthermore, it is a downstream water user and shares trans-boundary water resources along common borders with Saudi Arabia and the Sultanate of Oman, 350 km and 280 km in length respectively.

Water resources development within the Emirate can be tracked back to the Stone Age, commencing 3000 BP, through the Iron Age, the Islamic period and pre-oil times to the present day. Historically, sustainable water resource use was achieved by developing the groundwater obtained from shallow groundwater aquifer systems using hand dug wells, the traditional aflaj system and rainfall harvesting methods. Over the last three decades, however, rapid economic development, coupled with sharp population increases and the development of a large agriculture sector, sustainability supported by government subsidies, has lead to large increases in water demands. A reduction in the groundwater table has caused numerous shallow wells to go dry and the almost total cessation of natural groundwater flow within the aflaj systems. This has meant an increasing reliance on non-conventional water resources, such as desalination and reuse of treated wastewater resources, and also the development of alternative conventional water supply measures such as recharge dams, storage dams, recharge wells, interception of groundwater losses and water transfers from other Emirates. With water use now being twenty five times larger than the total annual renewable water resources of the Emirate, there is an urgent requirement for important integrated water resources management in order to achieve sustainable development within the water sector.

The water resources in Abu Dhabi can be classified to two main categories:

- Traditional or Conventional Resources: rainfall, springs, aflaj, wadies, alkes, ponds, and groundwater.
- Non-Conventional Resources: desalination and treated wastewater.

Groundwater occurs in the Emirate as either consolidated or unconsolidated surficial deposit aquifers or as bedrock/ structural aquifers and contributes 71.5% to the total water demand, followed by desalination 24% and treated wastewater 4.5%. It is estimated that there is still 640 KM^3 of groundwater resources available, but less than 3% is fresh and, based on current abstraction rates, both fresh

and brackish reserves will be depleted within 50 years. Numerous wellfields abstract groundwater of various qualities and in some areas massive over-abstraction has resulted in alarming groundwater decline and a severe deterioration in groundwater quality. The water policy in the Emirate has been largely based on supply, rather than demand management, through the construction of numerous, expensive desalination plants. This policy has led to the current high levels of per capita water consumption in the Emirate (550 l/c/day) which is more than double that of developed, European countries which have much greater available water resources.

Overall water scarcity and ongoing depletion and potential for pollution (especially Nitrates from the extensive use of inorganic fertilizers) of the Emirate's useable, natural (ground) water resources, which have arisen from rapid social /economic development in the last four decades has placed considerable stress on sectoral water use. Unplanned and uncontrolled groundwater withdrawals, especially in the agriculture and forestry sectors, now total over 2.6 billion cubic meters per year and have resulted in declining groundwater levels and quality in many areas. The water policy in the Emirate has been largely based on supply, rather than demand management, and now relies on numerous, expensive desalination plants to supply drinking water.

In the past, lack of regulation and control on the development of water resources has been largely responsible for the current poor water situation, and since no single authority had the mandate for water resources management, water resources development has been largely adhoc and unplanned, and duplication of efforts has lead to wasted resources. Recent changes in assigned responsibility for the various aspects of water resources development and management in the Emirate has now created the opportunity for improved Integrated, Water Resources Management (IWRM) and the outlook is much brighter.

In 2005, the newly formed Environment Agency – Abu Dhabi (EAD) was assigned total responsibility for groundwater management, and during 2005 and 2006, the new and enlarged water resources department have commenced projects which focus on the following activities, all of which are essential to effective IWRM:

- Protection, conservation and monitoring of water resources
- Continuous monitoring for the exploitable groundwater aquifers
- Planning, policy-making and regulation of water use
- Water well inventory and registration
- Management of data and information on water (establishment of a centralized water resources database)
- Development of Abu Dhabi Water Master Plan
- Developing the water policy including the development of the first plumbing code and using new water saving technology
- Coordinated groundwater exploration and assessment
- Capacity-building and institutional development within the water sector
- Local, regional and international cooperation and collaboration
- Management of strategic emergency water resources
- Using new irrigation technology such as subsurface irrigation and root hydration system
- Using solar thermal technology for desalinating the brackish groundwater

As a major step towards controlling groundwater development, a water well drilling Law was established in March, 2006 and the well permitting policy is managed by EAD. As an integral part of the controlling groundwater development and well permitting, a system for registering the water well drilling contractors and consultants was established. In late 2005, EAD also established a groundwater monitoring network and in May, 2006, work commenced on the development of a comprehensive water resources database for the Emirate. In the second half of 2006, an Emirate wide program of water well inventory and registration commenced. Other important actions to be considered as priority for improving the current water situation are:

- Replacing the use of inorganic fertilizers with organic farming;
- Revision of the agriculture and forestry policy in the light of dwindling groundwater resources and increasing reliance on desalinated water;
- Increasing tariffs (price increases as consumption increases) and installing water meters in order to assess the present water use in domestic sector and curb water waste and reduce per capita consumption;
- Raising the public awareness on water conservation and efficient water use;
- Encouraging the industrial users in water recycling and reuse of treated wastewater in activities that don't require potable water;
- Special care should be given to monitoring, evaluating, modeling and sustainable development of groundwater resources, especially to stabilize the over-exploited aquifers;
- Implementing artificial recharge to enhance groundwater storage.

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1 Introduction

Abu Dhabi Emirate, one of the seven Emirates which comprise the United Arab Emirates (UAE), occupies an area of 67,340 km², or about 80% of the total area of U.A.E (Error! Reference source not found.). The Emirate has an arid climate with less than 100 mm/yr average rainfall, a very high evaporation rate (2-3 m/yr), a low groundwater recharge rate (<4 % of total annual water used) and no reliable, perennial surface water resources. Furthermore, it is a downstream water user and shares trans-boundary water resources along common borders with Saudi Arabia and Sultanate of Oman, 350 km and 280 km in length, respectively.

Historically, all the Emirate's water requirements were met solely from groundwater obtained from shallow hand dug wells and traditional Falaj systems, comprising man – made channels used to collect groundwater, spring water and surface water. The water was then transported, by gravity, to demand areas. Over-pumping practices have resulted in a severe decline in groundwater levels and quality deterioration. Increasing of groundwater salinity along with high evaporation has led to increases in the salinity of agricultural lands due to the accumulation of salts on the ground surface. It has also affected the efficiency of the irrigation system and minimized its lifetime resulting in increasing the investment in drilling new wells and rehabilitation of the irrigation systems infrastructure. Over the last two to three decades, however, rapid economic developments, coupled with sharp population growth and the development of large agricultural areas, substantially supported from government subsidies, has led to an increasing reliance on unconventional water resources, such as desalination. Alternative conventional water supply systems, such as recharge dams, storage dams, recharge wells, interception of groundwater losses, re-use of wastewater and water transfers were also developed. With water use now being twenty five times larger than the total annual renewable water resources of the Emirate, there is an imminent need to coordinate the current activities of different organizations in the fields of water supply and use to achieve the sustainable development within the water sector. Also, the need for rational water management plan is critical.

The purpose of this sector paper is to provide a comprehensive review of the water resources in the Emirate of Abu Dhabi. It discusses issues, challenges and opportunities associated with the management of available water resources, and presents an outlook for the future. The paper defines all water sources and users up to the year 2007, the year for which a complete data and information set is presently available. It also highlights problems associated with current water management practices and provides an outlook for future practices in the management of the Emirate's valuable water resources.

Figure 1: General Location of Abu Dhabi Emirate

2 Historical Background

Water resources development within the Emirate can be traced right back to the stone age, commencing 3000 BP, through the iron age, Islamic period and pre-oil times to present day. Shallow hand dug wells (only a few meters deep) and traditional irrigation canal systems (aflaj) provided permanent water sources used for sustainable agriculture and drinking water supply.

The shallow hand dug wells were constructed both onshore and on offshore islands. Examples of late Stone Age (c. 5,000 BC to 4,000 BC) and early Islamic period (620 AD to 1800 AD) dug wells are found at the present site of Abu Dhabi International Airport and also on Marawah Island respectively as shown in Figure (2). In areas of shallow water tables in the surficial, alluvial and sand aquifers, hand dug wells and open pits for water abstraction are still constructed today as shown in Figure (3).

Figure 2: Early Islamic period well on Marawah Island

(photo courtesy of ADIAS)

Figure 3: Modern Hand dug well/pit at Al Khatim Island

The history of aflaj development within Abu Dhabi, and the UAE as a whole, has been well documented by Al Tikriti (2002). A review of the current status of aflaj and oases is provided by Al Ain Municipality and Agriculture (2004a). Aflaj can be traced back to the Bronze Age, although the majority of sites date back to the Islamic period. Three types of aflaj are known as shown in Figure 4; namely:

Aini (originate from springs and are perennial in nature) al qanat al jawfîyaDawoodi (formed from sub-surface channels. Either lined or open)

Ghaili (Surface water or base flow diversions) al qanat al mahfûra

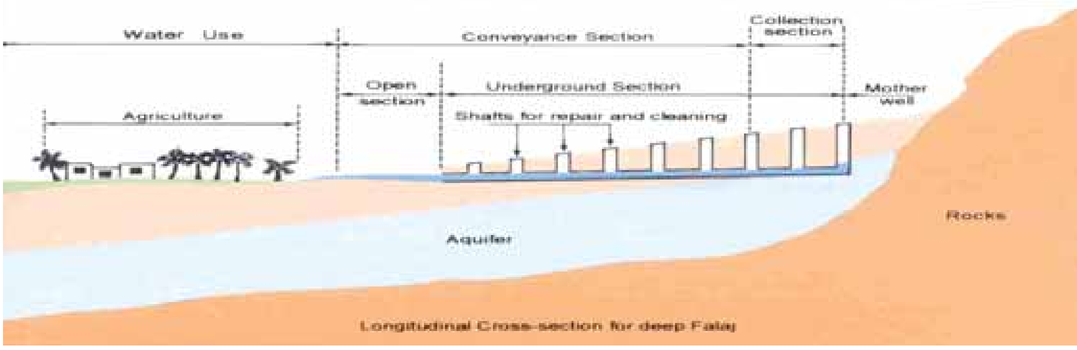


Figure 4a: Dawoodi Falaj

Figure 4b: Aini Fala

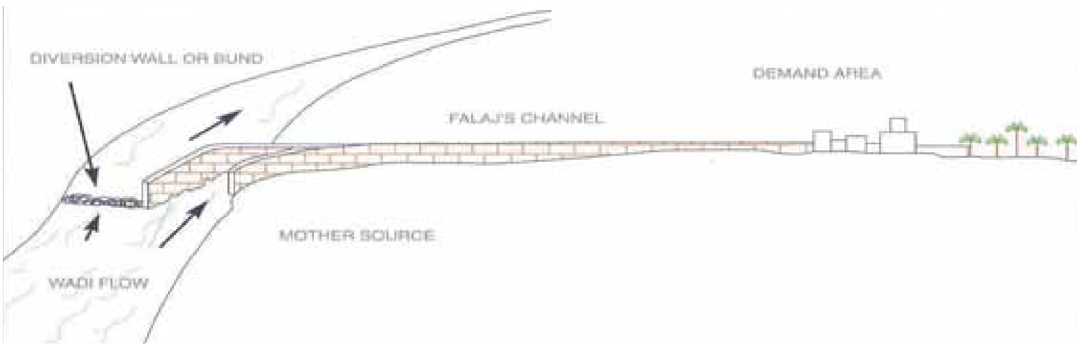


Figure 4c: Ghaili Falaj.

Aini Aflaj water sources are invariably springs which develop due to impervious bedrock exposures. Dawoodi aflaj are subterranean and are constructed channels which are accessed via vertical shafts known as thaqba. Their source is a mother hand dug well which feeds the main channel by gravity. The Ghaili falaj is a channel which is fed by bunding and diversion of a surface water supply, most often an active wadi bed or a spring.

Many Islamic period aflaj irrigation systems continued to be used until pre-modern times and were regularly cleaned. The Iron Age aflaj have, however, long since fallen out of use and are now covered and abandoned.

Aflaj in Abu Dhabi Emirate have only been developed in the region of Al Ain City, which are fed by recharged alluvials bordering the Oman Al Hajar Mountains as shown in Figure (5). Today, all twelve aflaj under the management of the Aflaj section of the Parks and Gardens Dept of Al Ain Municipality and Agriculture are either partially or wholly supported by boreholes. Al Dawoodi falaj is now supported by a wellfield of 87 wells, drilled at 16m spacings. Table (1) shows that 21 aflaj that are found in the Al Ain region. Al Hili and Al Raki aflaj are the oldest and both are around 3000 years old and were constructed in the Iron Age. Of the twenty-one aflaj that have been inventoried, only nine are currently in operation (Al Tikriti, 2002 and Dawoud, 2007).

The Aflaj in Abu Dhabi Emirate have only been developed in the region of Al Ain City, which is fed by recharged alluvials bordering the Oman Al Hajar Mountains. Today, all nine working aflaj fall under the management of the Aflaj section of the Parks and Gardens Dept of Al Ain Municipality and Agriculture and are either partially or wholly supported by varying support from boreholes, piped desalinated water and treated effluent from the Al Zakher Sewage treatment plant. In 2004, the plant supplied a total of 21.7 Mm³/yr of tertiary treated effluent for irrigation of Al Ain's green areas, however the amount supplied to aflaj is unknown.

Figure 5: Present day Oases in Al Ain City.

Table 1: Summary of recorded aflaj in Al Ain

Falaj Name	Location	Mother Well	Depth (m)	Length (km)	To Irrigate	Status
Al Aini or Al Saroj	Sahal Al jaw – Marag SE of the City		20	15 km	Al Nakhil oasis	supported by 24 wells in Aini & Daoudi and desalinated water
Al Daoudi	Shabaihat		20	7 km	Al Ain oasis (129.53ha)	supported by 24 wells in Aini & Daoudi and desalinated water 147,120 date trees
Al Mutared	N of Al Muraba tower Al Ain City Center				Al Mutareth Oasis (26.22ha)	supported by 9 wells to irrigate 40860 date tress and TSE
Al Qattara	Al Buraimi,Oman				Qattara Oasis (47.62ha)	supported by wells to irrigate 40880 date trees
Al Jimi	Al Buraimi,Oman				Al Jimi Oasis (77.27ha)	supported by wells and TSE to irrigate 70740 date trees
Al Hili	Starts from Al-Oha N&E of the City	Sahal Al-meairij	30	10 km	Hili Oasis (51.1ha)	supported by 26 wells and desalinated water to irrigate 54145 date trees
Al Muwaiji	City Center at Al Kuwaitat			6 km	Al Muwaijei Oasis (17.99ha)	supported by wells to irrigate 20950 date tress
Maziyad	Maziyad	Maziyad,Western Safafa	24			supported by wells
Al Jahili	Al Ain City Center				Al Jahili area	trace
Saa	Al Dhaher Area				Saah Area	abandoned
Wadi Al Hamam	Al Hili- Bidi bint Saud		6.5			abandoned
Wadi Al Jabeeb						abandoned
Al Hili Fun City						abandoned
Al Raki	NE Al Ain city					dry
Al Masoudi	Al masoudi				Al masoudi area	dry
Hazza		Al Hamala			Al towaisa in Al manaser	dry
Al Gashabi	N&E of Al-Oha				Al Hili	dry
Al Meatelej					front of al Hili	dry
Al Henyami	N of Al Ain City				S of Al Hili	dry
Al Khazami	N&E of Al Hili					dry
Umm Al Mader	NE of al Hili	Umm Al Madder			Al Hili	dry

References: Dawoud (2007), Al Tikriti (2002) and Al Ain Municipality and Agriculture (2004a).

The late great Sheikh Zayed bin Sultan Al Nayhan placed major eeforts on the preservation of these Oasis areas and they were considered as an important part of the heritage and culture of the area and are thousands of years old. They also, along with the traditional aflaj irrigation canals, provide important places of interest for the growing tourism industry in the area.

The mother wells of the Dawoodi aflaj range in depth from 6.5 to 30 m. Al Aini falaj is the longest with a channel length of 15 km. Two, old aflaj at the Al Hili archaeological site have been excavated and are dated to the Iron Age. A similar excavation programme at Bida bint Saud has also dated a falaj there at Iron Age.

Whilst all flowing aflaj in the Emirate are now supplemented with boreholes, there are approximately 30 active aflaj in the Northern Emirates, mostly Aini type, originating from springs in the Ophiolite Complexes e.g. Masafi, Hatta etc. By contrast, in neighbouring Sultanate of Oman, there are a total of 4112 aflaj registered in the national aflaj inventory (MRMEWR, 2001), of which 3108 flow under natural conditions. The aflaj of Sultant of Oman are still supplying one third of the countries total water demand. Oases were traditional centres of both habitation and agriculture, originally fed by naturally flowing aflaj. Figure 5 shows the Al Ain oases areas of today. It is estimated that combined, they consume about 10 Mm^3/yr of irrigation water for around 375,000 date palm trees and occupy an area of 350 Hectares. The largest oasis area, Al Ain, occupies 130 ha. The present day Oases areas have now shrunk. In early Islamic times, the combined oasis area, called Tuwwâm, was much larger and was one of the regions most important social and cultural centres.

Over the last 20-25 years the aflaj of the Al Ain region have been placed under increasing stress from declining groundwater levels in the source or mother well areas, whilst the water table in the vicinity of the aflaj shari'a itself has steadily risen in recent years due to artificial recharge of groundwater from treated sewage effluent (TSE) and desalinated irrigation water which is now widely used to keep the garden city of Al Ain green.

For the last 3,000 years or so, aflaj have provided for sutstainable agriculture and civilisation in the Al Ain Region. However, today, only two of the seven operating aflaj have natural flow and all afalj are supported by varying mixtures of pumped groundwater from wells, imported desalinated water from Qidfa desalination plant, Al Fujairah and, more recently, from TSE, the latter supply generally being small and unreliable. Today the aflaj are used for irrigation of the six main oases which occupying about 5% of the total green area of the city.

The Al Aini and Daoudi Aflaj have by far the strongest natural flow but around 50% of their total flow is supported. All other aflaj rely on support for their flow. Given the various sources of water input to the falaj means that the falaj water quality is never consistent, only in the case where the falaj are supported primarily from one source e.g. Al Qattara only from groundwater. The TDS of aflaj water sampled as part of a recent study (Dawoud, 2007) ranged from 380 mg/l (Al Aini – largely supported by Desalinated water) to 2820 mg/l (Al Mutarid – supported by groundwater wells and TSE as shown in Figure (6).

Despite the difficulties in maintaining the aflaj flows, the strategy of Al Ain Municipality is that the support to the falaj systems shall continue indefinitely, as per decree by the late Sheihk Zayed bin Sultan Al Nayhan, and that the area of oases which they support shall be preserved at all cost. The aflaj and oases are an integral part of the historical culture of Al Ain City, which is rich in archaeological heritage.

A total of 96 groundwater wells currently provide support to the aflaj in addition to about 1,6 million gallons per day desalinated water and a small, unquantified amount of treated effluent (TSE). The amount of TSE available for support to the aflaj will increase over the next 5 years since it is the strategy of the Municipality to replace all groundwater used for irrigation with TSE as part of the Al Ain Master Plan.

Jorgensen and Al Tikriti (1995 and 2002), from a hydrologic and archeological study of climate change in the Hili area of Al Ain, have shown that trends of increased well depths and declining water levels for the past 4,500 years correlate with an increase in aridity of climate. Figure (7) shows a 4,500 year hydrograph with a slow groundwater decline from 2,500 BC to ca. AD 1650, an increased rate of decline then to around AD 1900, after which there is a very rapid decline that is largely anthropogenic. The increase in aridity experienced in Abu Dhabi Emirate represents a trend which existed over all or most of the Middle East, eastern Mediterranean and northern Africa which had an immense impact on civilizations. In the Al Ain area, non-irrigation farming could not successfully be sustained at the end of the Bronze Age. This hindered economic development until the aflaj system was introduced in the Iron Age.

The Liwa Oasis, in the Western region, is the other traditional area of agriculture found in the Emirate of Abu Dhabi. Immediately south of the Liwa crescent, there is evidence of late Islamic and Late Stone Age habitation (Harris, 1977). Fresh water was obtained from shallow dug wells within the sand dune aquifers. There is evidence also offshore, on Marawah Island, of ancient water use in the form of rainfall harvesting. Gulleys have been constructed to capture run-off and channel it to wells. Six late Islamic period wells have been located about 1km west of the village of Ghubba on Marawah Island.

The modern period commenced with the discovery of oil in Abu Dhabi Emirate in 1958 and with its first export in 1962. The last half century has witnessed incredible economic development and massive annual increases in water use, largely sourced from abstractions from groundwater. Furthermore, the introduction of the more efficient electric submersible pump in the early 1980's, as a replacement for lower yielding diesel engine turbine shafted pumps, in the agriculture and forestry sector in particular, has accelerated groundwater productivity, but at the expense of aquifer sustainability. In the absence of sound,groundwater management policies, abstractions have continued unregulated with severe consequences of declining groundwater levels and substantial increases in groundwater salinity in some areas and also widespread groundwater pollution associated with agricultural practices. Another ancient falaj has been discovered west of Bida bint Saud as shown in Figure (8). Several shaft holes and a subterranean tunnel were excavated at different spots. The most important was the discovery of the sharia, which, according to the local pottery found, is of Iron Age. An approximate date of 1000 BC was given to this falaj as well as to a near-by structure.

Figure 6: Al Mutarid source channel.

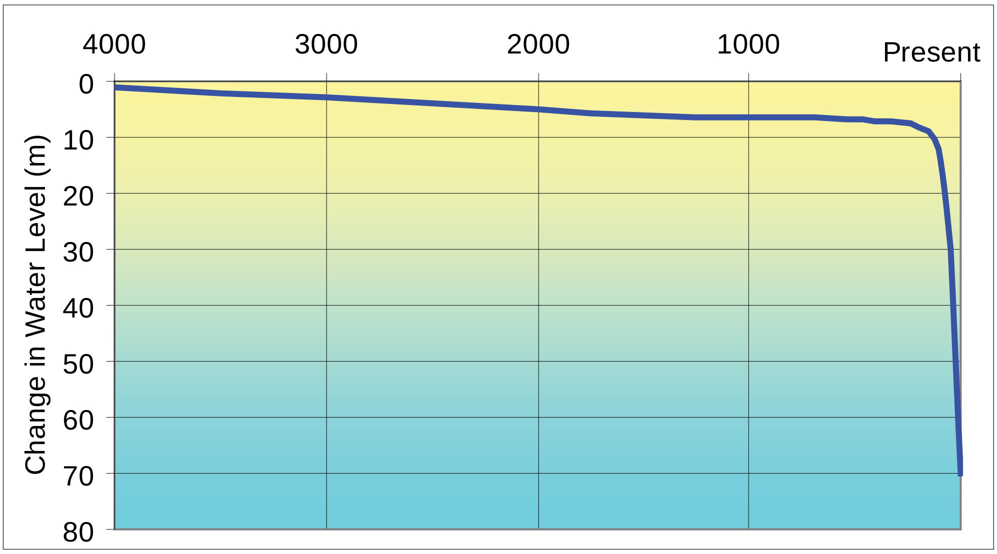


Figure 7: Changes in groundwater levels at Al Ain over the last 4,000 years.

Adapted from Jorgensen & Al Tikriti (2002)

(a) (b) (c)

Figure 8: Archaeological digs at Aflaj in Al Ain (courtesy of Al Ain National Museum)

(a) Hili, (b) Bida bint Saud Falaj, (c) steps down to Shari'a at Bida bint Saud Falaj

3 Physical Settings

3.1 Location and Population

The Abu Dhabi Emirate has a total area of about 67,350 km^2, and is located in the southern part of the Arabian Gulf. It represents part of the unstable shelf of the Arabian foreland. Conditions in the Late Paleozoic and throughout much of the Tertiary were conducive for fairly uniform deposition of eperic shelf carbonates, which were associated with minor clastics and evaporites that reflected major cycles of transgression and regression. Sedimentation patterns were controlled by prominent regional structural features, epeirogenic movements and/or eustatic sea-level fluctuations. The tectonic history of the area is connected with the opening during the Triassic, and closure during Upper Cretaceous-Paleogene of the southern Neo-Tethys Ocean. The total population of Abu Dhabi Emirate is about 1.292 million according the senses of 2006 as shown in Table (2).

Table 2: Population of Abu Dhabi Emirate (2006).

Area	Population
Western Region - Abu Dhabi	858650
Eastern Region - Al Ain	422340
Islands	11129
Total	**1,292,119**

3.2 Climate

Abu Dhabi Emirate generally has a semi arid to arid climate characterized by a prolonged dry summer period of very high temperatures between April – November and a winter period between December and March of mild to warm temperatures with slight rainfall. In the summer months, the weather conditions are very humid and hot with daily average temperatures of 35 °C and the average rainfall is only about 2 mm. The land-sea breeze circulation dominates the wind regime for most of the period. The sea breeze brings cool air from sea to land but the associated increase in humidity keeps the weather conditions uncomfortable. Earlier in summer, during May and June, a North-westerly flow of air develops over the Arabian Gulf in response to a trough of low pressure (Indian Monsoon) across Pakistan and into Iran. This condition is known as the summer shamal which delivers relatively cold air, so it brings relief from the very hot weather conditions. Local instabilities can produce thunderstorms which usually provide light rainfall, especially over the neighboring Oman Mountains.

The four winter months have unsettled weather and provide most of the rainfall. The coolest month is January, with an average temperature of 18 ˚C and the wettest month is February, with an average rainfall of 30 mm whilst March has the highest number of rainy days.

Rainfall is highly variable in time and space. Most of the rainfall in winter occurs as a result of convergence zones caused by an upper level trough to the west of the Gulf area. Short, heavy rainfall produces the best opportunities for aquifer recharge. Runoff occurs in the non-vegetated Oman Mountains and collects in wadis which drain into the U.A.E, eventually recharging the shallow alluvial gravel aquifers.

Sunshine

The sky over the Emirate remains virtually cloud free for most of the year. The mean daily sunshine totals for Al Bateen are shown in Figure (9). There is no month with fewer than seven hours of sunshine per day and in summer this rises to over 10 hours. The drop in sunshine during July and August is due to the presence of cloud drifting over from the Indian monsoon. It is only the shorter length in daylight hours at this latitude that limits the daily totals. On average 80% of possible sunshine is recorded. Sunshine figures are fairly similar throughout the Emirate, but slightly higher figures can be expected in the south-western areas away from the coast.

Cloud

For much of the year there are only small amounts of cumulus and stratocumulus cloud forming during the daytime; the base of these clouds is around 3,000 feet (1,000 in). Cloud amounts increase in the winter, especially during a shamal, when cold air moving south from Iraq becomes unstable due to warming by the Gulf waters. Low cloud also occurs in association with fog and during periods of heavy rainfall. Cloud amounts gradually decrease away from the coast as the sea air becomes modified. Cumulonimbus clouds can be present during the passage of an active weather system and their development can be vigorous if conditions are favourable. In summer, cumulonimbus clouds sometimes develop in the afternoon over the Hajar Mountains. Medium level clouds, such as altocumulus and altostratus, generally affect the Emirate during unsettled spells of weather and are the main source of rainfall during the winter months.

These types of cloud are occasionally seen in the summer when the upper winds over the Emirate become easterly, allowing cloud to drift over from the Indian monsoon. High level clouds such as cirrus and cirrostratus are usually only seen in the winter in association with the Sub-Tropical Jet Stream.

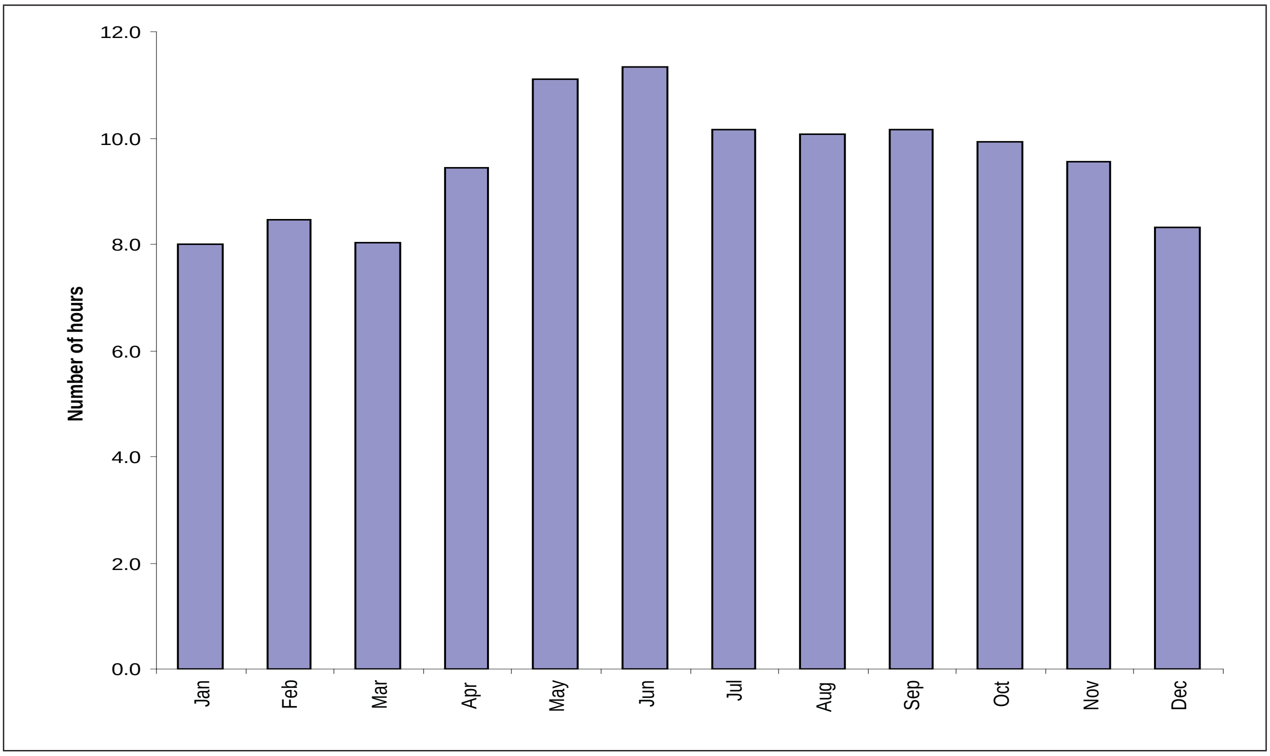


Figure 9: Mean monthly sunshine hours per day at Al Bateen Airport (1973-1997).

Evaporation

The combination of high temperatures, low humidity and long hours of sunshine leads to extremely high monthly evaporation rates as shown in Figure (10). During a year when winter rainfall is above average, it is possible in January and February for rainfall totals to exceed the amount of water lost by evaporation. By the beginning of the summer, however, the benefits of any earlier rainfall are wiped out as monthly evaporation rates exceed 300 mm from May to August.

These high evaporation rates only apply where there is a constant supply of water, such as over the sea. Inland, the actual amount of water lost by evaporation will be fairly small due to the lack of surface water and vegetation. The level of the groundwater below the surface will also affect how much water is lost through evaporation.

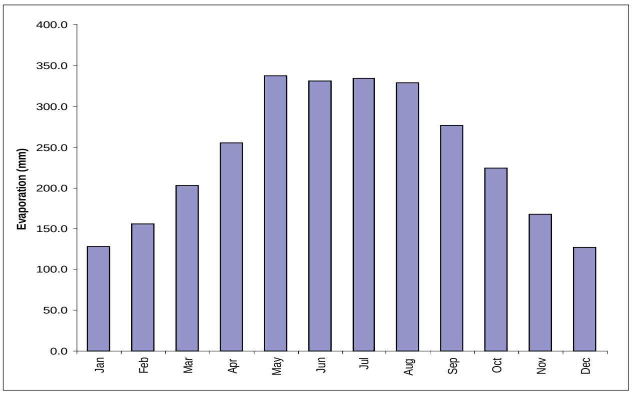


Figure 10: Mean monthly evaporation at Al Bateen Airport (1981-1997).

3.3 Precipitation

The Arabian Peninsula is located within south west Asia, which is delineated by five bordering seas, namely, the Mediterranean and Red seas to the west, the Caspian and Black seas to the north and the Arabian sea to the south. These five water bodies represent the potential water vapor sources for this region. However this supply is restricted by the prevailing pressure patterns and the restraining influences of the massive mountainous ranges surrounding the region. The mountains act as barriers to any cold air masses that may initiate weather activities. In addition, the Sub-Tropial Anticyclonic cell that dominates in the middle and upper troposphere inhibits cloud formation and hence leaves the general area with very little rainfall. The weather situations that give rainfall to Abu Dhabi Emirate can be summarized as (DWRS, 2002):

During winter months (majority of rainfall events)

1. From cloud bands that migrate from the eastern coast of Africa, induced by well defined upper troughs over the middle latitudes (provides 80% of all UAE rainfall); years with rare rainfall are associated with fewer such cloud migrations.

2. From the frontal systems that originate in the Mediterranean, when the Siberian high pressure shrinks northeastwards by late winter, these systems may have tracks across the Gulf sea; such frontal systems give rainfall and thunderstorms over the UAE but the amount over Abu Dhabi Emirate is less than other Emirates, since the winds associated with such fronts pass parallel along the Abu Dhabi coastal line and not perpendicular as the with the other Emirates.

3. Due to the southward advance of active westerly troughs over the south western part of the Arabian Peninsula. The troughs bring cold air masses that meet and converge with relatively hot and humid air from the south. These situations lead to the most vigorous and unstable weather conditions with often result in heavy rain.

During summer months rainfall can be associated with:

1. Clouds drifting from the Indian monsoon over the Arabian Sea.

2. Afternoon convective clouds due to orographic effects, especially in the eastern region of Abu Dhabi Emirate e.g. Al Ain area.

3. Rare cases of the Inter Tropical Convergence Zone shifting northward over UAE and causing overcast weather and thunderstorm activity.

4. The temperature contrast between land and sea (at the hottest time of the year) which may be large enough to produce what's known as a sea breeze front that may give traces of rainfall along the coast.

Precipitation in Abu Dhabi Emirate, as in similar arid and semi-arid zones, results largely from convective cloud mechanisms producing storms typically of short duration but with the following characteristics:

- Great variability (above 70 %) from year to year; e.g. one or two successive years with appreciable rainfall amounts, then followed with years with less or no rain.
- One day precipitation may exceed the total precipitation of 2 or 3 years.
- The 24 hours rainfall in two nearby stations may differ significantly. For example, on the same day in 1988 rainfall at Abu Dhabi International Airport was 120mm compared with 81.5 mm in Bateen Airport, located 30 km apart. Figure 11 shows the variation in rainfall at three locations in the Emirate.

Rainfall within Abu Dhabi Emirate is erratic both in time and space, but provides the source of water for runoff which eventually results in recharge to aquifers, especially in the eastern region of the Emirate, where numerous wadi systems, crossing over the borders from Oman, provide for preferential pathways which allow rapid percolation to underlying surficial sand and gravel deposits. Whilst this recharged water is very important, it contributes, on average, only 4 % per annum to the total water consumption in the Emirate.

A network of meteorological stations is operated by the Department of Atmospheric Studies (DAS -formerly DWRS) within the Ministry of Presidential Affairs (DWRS, 2002-2004), the Meteorological Department within the Ministry of Communications, EAD and the NDC/USGS Groundwater Research Project in Al Ain. Real time weather data is available on line from DAS at their web site http://www.das.ae/.

Orographic effects are clearly seen on the rainfall distribution. The Al Hajar Mountains in neighbouring Oman, which reach elevations in excess of 2000 (mamsl) generate high rainfall incidents, especially in the winter months, which provide for the runoff to wadis which cross over the boarder into Abu Dhabi Emirate. Within Abu Dhabi, this high elevation rain occurs only at Jebel Hafit, which, at an elevation of 1163 (mamsl), is the highest point in Abu Dhabi Emirate and the only high mountain massif within the Emirate. Mean annual rainfall within Abu Dhabi Emirate varies from 46 mm at Jebel Dhana in the western region to 119 mm at Al Wigan, south of Al Ain, in the eastern region. The mean annual rainfall at Al Ain 1971-1994 is 96.4 mm with a maximum of 303 mm/yr. The mean annual precipitation for Abu Dhabi Island is 87 mm, with a maximum of 227 mm/yr.

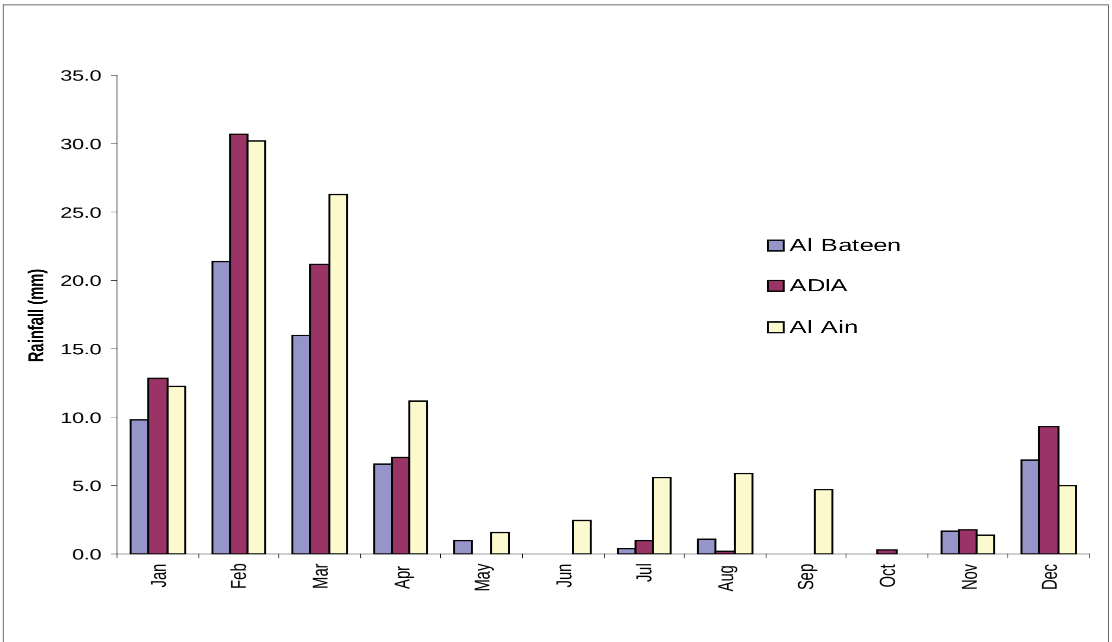


Figure 11: Mean monthly rainfall at Al Bateen Airport (1971-1997), Abu Dhabi International Airport (1982-2000) and Al Ain Agricultural Station (1971-2000).

3.4 Physiography

A brief description of the physiography of the Emirate is provided in this section. The Physical Geography Sector Paper will give a detailed account and other detailed descriptions can be found elsewhere (UAEU, 1993, USGS/NDC, 1996). The land surface features of the Emirate are striking in their variety and the following natural, geomorphologic settings can be found: Tidal flats and channels, fringing coral reefs, coastal terraces, ancient raised beaches, salt dome islands, barrier islands, ancient and recent coastal and inland sabkha, sandy beaches, fluvial terraces, palaeolake remnants, delta remnants, a whole multitude of sand dune types and features (longitudinal, linear, mega barchans, small barchans, transverse, compound linear, rectangular linear, palate – aeolianite,) flat topped hills, high, jagged jebels, alluvial fans, playa, gravel plains and wadis. In addition, artificial depositional islands and areas are found, especially in the vicinity of Abu Dhabi Island, e.g. Lulu island, etc.

A simple classification of geomorphology has been undertaken by the United States Geological Survey (USGS/NDC, 1996) in accordance with regions of hydrological significance, as shown in Figure (12) and Table (3). At 1163 meters above mean sea level (mamsl), Jebel Hafit is the highest point within the Emirate. Located in the piedmont plain region, it, along with the Oman Al Hajar Mountains just across the UAE- Oman border, provides runoff from rainfall to actively recharge a number of significant wadis (10 major) which enter the Emirate from the east, the most northern of which, is Wadi as Sumeni. A number of potable wellfields still exist in regions IIf and III (Figure 12) and benefit from rapid recharge of very fresh runoff water from surface wadi and buried alluvial channels.

Region II is the largest and comprises internal sand dunes (dominant landform) and sabkhas. Various alluvial and widespread sand aquifers occur, but are not actively recharged today; however, they still contain large amounts of fresh groundwater that were recharged from previous pluvial periods. The barchan dunes, south of the Liwa crescent, can reach over 100m in height and enclose depressions of sabkha, some of which have surface water present.

The coastal marine zone I stretches from As Sila to Ghantout, a distance of over 350km. This zone has little hydrological significance; it comprises hyper-saline sabkha aquifers mostly and consequently has very little groundwater development. No groundwater development is known from any of the offshore islands included within or opposite the coastal zone; rather, water supplies are obtained from small to medium sized desalination plants which use seawater as a source. A coastal sensitivity atlas was produced in 2002 (ERWDA, 2002a) which describes the various classifications of coastal features and their susceptibility to pollution from accidental oil spills, for example.

Table 3: Geomorphic units and hydrological significance

Region	Sub region	Area (Km²)	Features	Hydrological significance
I Coastal Marine	a	6500	Tidal Flats, sabkha coastal terrace	Sabkha aquifer, hyper-saline
	b	4000	Tidal Flats, sabkha, fluvial terrace	Sabkha & Saline sand aquifer
	c	2900	Tidal Flats, sabkha, paleodunes	Sabkha & Saline sand/gravel aquifers
II Internal Dune sand	a	2500	NE-SW longitudinal dunes, 20m high	Various surficial alluvial and sand Aquifers, limited bedrock groundwater potential
	b	13300	NW-SE longitudinal dunes, 30m high	
	c	9800	NE-SW transverse dunes, 40m high	
	d	3900	Barchan dunes, 100m high, & sabkha	
	e	3300	NW-SE rectangular-linear dunes, sabkha	
	f	11400	E-W compound linear dunes, 60m high	
III Piedmont Plain		900	Alluvial fans, gravel plains	Active recharge/runoff in wadis, significant bedrock groundwater potential

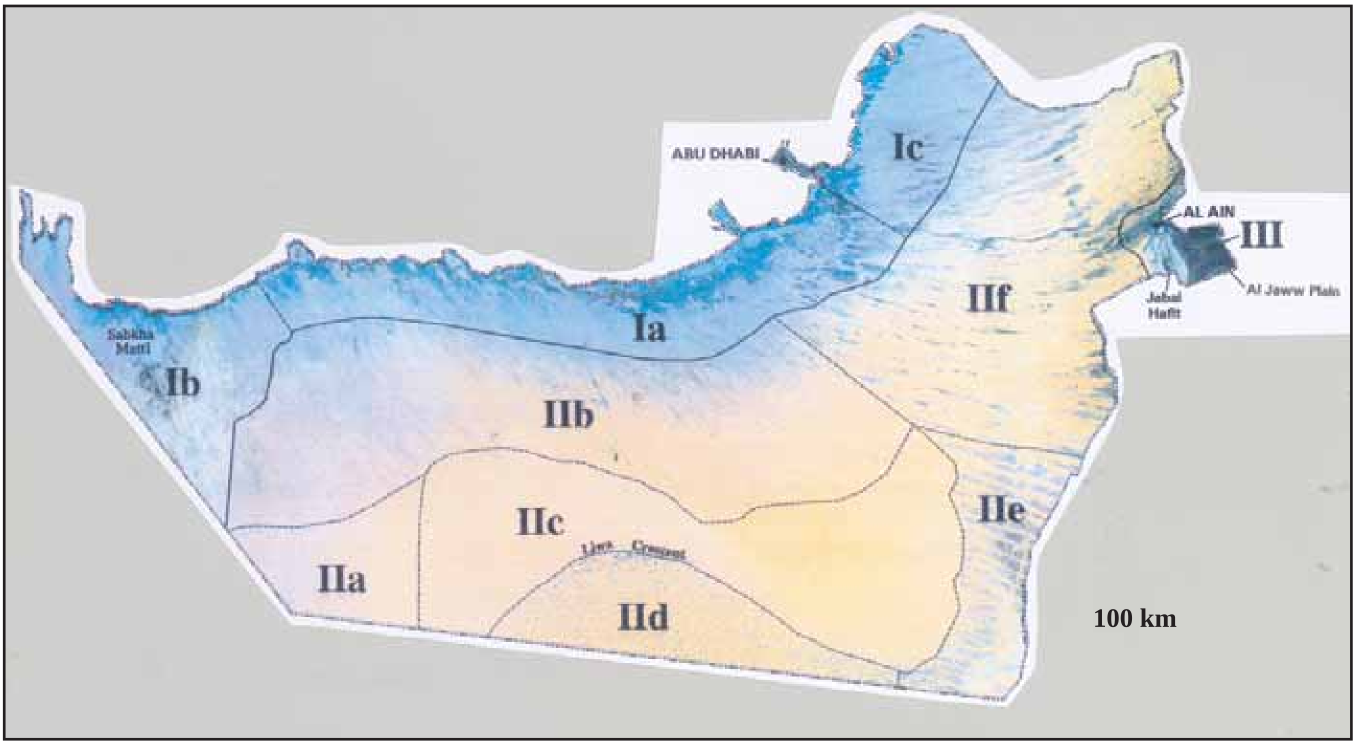


Figure 12: Physiographic regions of Abu Dhabi Emirate
(USGS.NDC, 1996).

4 Hydrogeological Settings

4.1 Geology

Abu Dhabi can be divided into four geological/ geomorphological regions:

(1) Many islands and the Jebel Dhanna Peninsula salt plugs with associated Precambrian Hormuz rocks (gypsum anhydrite, shales, siltstones, granites, gabbros) and younger sediments of Neogene and Quaternary age. Diapiric salts are believed to underlie most of the structures of Abu Dhabi;

(2) A coastal area and barrier islands complex mainly formed by coastal sabkhas and Miocene-Pliestocene sediments rich in Miliolids. These coastal sabkhas are composed of calcareous silts and muddy sands with displacive sulphate nodules crystals and halite salt crusts. These are flooded by storm and spring tides and occasional wadi runoff.

(3) The inland area (the desert area) dominated by extensive gravel plains with aeolian sand dunes of different sizes and forms formed by the prevailing winds, inland sabkhas and scattered Neogene outcrops. The largest inland sabkha occupies the lowland known as Sabkhat Matti, which is located in the western part of the country, and extends inland from the coast for about 120 km, reaching a height of over 40 m above sea-level at its southern tip; and

(4) The Al-Ain area lies in the marginal zone of the Oman Mountains with sedimentary sequence ranges in age from Late Cretaceous to Quaternary. Tertiary sediments (Paleocene-Miocene) have a vast extension in the Al-Ain area, overlapping the western flank of the Oman Mountain Zone. The Quaternary Piedmont Plains are large areas of fluviatile deposition extend outwards from the mountain region represented by boulders and pebbles in large alluvial fans and wadis.

The generalized geologic map of the United Arab Emirates is shown in Figure (13). Desert sands and coastal sediments characterize the surface geology of the western and central part of the country, while to northeast a mountain range extends from Ras Al Khaimah to Al Fujairah and extend southward to Al-Ain region (the eastern provinces of Abu Dhabi Emirate). A classic carbonate-evaporite complex characterizes the coastal areas adjacent to the Arabian Gulf, whereas silisiclastics, minor carbonate sands, and local sabkhas characterize the coastal areas of the Gulf of Oman. Near the mountainous areas large areas of fluviatile gravel form a plain onto which aeolian sand have been transported by the prevailing wind. Much of the area is covered by sand dunes of varying morphology as shown in Figure (14).

The aeolian sand dunes include transverse, barchan and seif dunes complexes, and cover large areas and highly varied in type and orientation. This paper deals with the geology of Abu Dhabi Emirate supported by field study and Landsat image.

Figure 13: Simplified geologic surface map of the United Arab Emirates (after Alsharhan and Kendall, 2003 from the maps prepared by Hunting 1979)

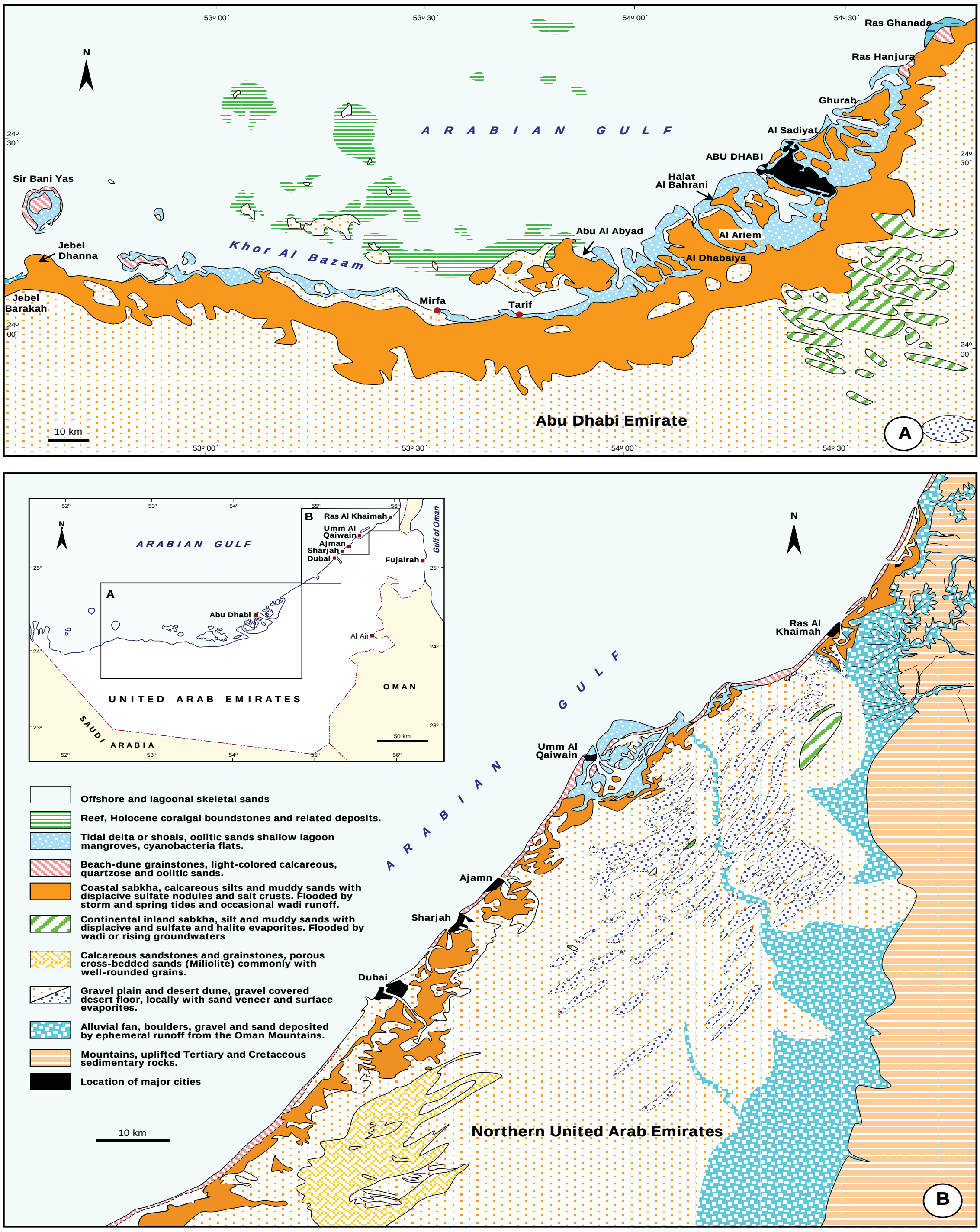


Figure 2. Simplified geologic surface map of the United Arab Emirates (after Alsharhan and Kendall, 2003 from the maps prepared by Hunting 1979). Small inset shows the relationship between locations of maps A and B.

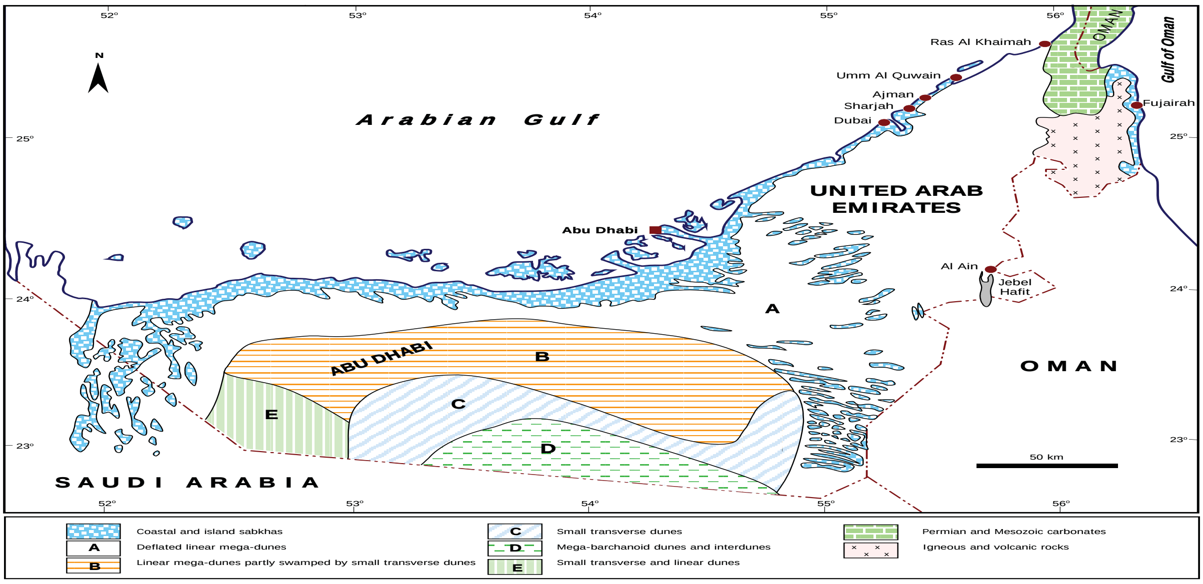


Figure 24. Distribution of different sand dunes in Abu Dhabi (simplified from Glennie, 1998).

Figure 14: Distribution of different sand dunes in Abu Dhabi Emirate

4.2 Stratigraphy and Paleogeography

A. Paleozoic

There is little data available to establish accurately the sedimentary history for the Lower Paleozoic in Abu Dhabi. The oldest rocks exposed in the Jebel Dhanna Peninsula and various coastal islands have been brought to the surface by salt diapers. These rocks are mainly a varied assortment of shales, dolomites, siltstones and volcanics (gabbro, granite, basic lava) correlatable with the Infracambrian Hormuz Series of Iran.

The Hercynian orogeny in the Early Carboniferous is believed to have caused uplift and erosion over most of the Arabian Gulf Area. The sediments laid down following this orogeny constitute a thick sequence of clastics, penetrated by deep wells and are named the Uanayzah (previously Pre-Khuff) Formation as shown in Figure (14). The formation is mainly composed of dark gray shales, siltstones, mudstones and minor claystone, underlain by a thick sequence of fine to medium-grained, cross-bedded, quartzose sandstones. These are interpreted to be of fluvial origin, and were probably deposited along point bars of meandering rivers.

Following clastics deposition, the climate became distinctly warmer and more arid. A carbonate-evaporite sequence accumulated over an epeiric shelf that was established across the whole region (Alsharhan and Kendall, 1986). From southern Arabia northward to central Iran, the sediments pass from continental through marine sands, into sabkha carbonates and shelf limestones. The character of the Late Permian shelf reflects an epeiric sea that covered the area, with such a low slope that even at its depositional centre, shallow-water conditions prevailed (Alsharhan, 1994). This Mid-late Permian sequence is known as the Khuff Formation, and represents a complex sequence of dolomite, limestone and anhydrite. The general lithology is of bioclastic lime mudstone and wackestones; interbeds of dolomitised oolitic packstones and grainstones; sucrosic dolomites associated with lime mudstones; and massive anhydrite and anhydritic dolomites. Dolomite is the dominant lithology of the formation (<75%). The formation was laid down in an unrestricted shallow-marine to restricted shoal-lagoonal and supratidal (sabkha) setting.

B. Triassic

Conditions became more arid in Upper Permian to Lower Triassic time, and the Arabian Shield was uplifted to the west, indicating periodic influxes of clastics onto the carbonate-evaporitic shelf. These conditions persisted throughout most of the Triassic. The Lower Triassic in the Arabian Gulf, was deposited in a continental and near-shore shallow-water setting, during a period of quiet sedimentation and minor tectonic activity. By the mid-Triassic, the basin was occupied by an evaporitic platform. During the Late Triassic, a relative fall in sea-level occurred, and was coupled with increased aridity, leading to the dominant deposition of continental clastics. A major period of uplift and erosion occurred, affecting the southern part of the Arabian Gulf. Continental clastic sediments are found only in onshore Abu Dhabi and the northern Emirates. In offshore areas of Abu Dhabi, Dubai and Qatar, there is no evidence of this section.

Triassic sediments can be divided into three formations (from bottom to top) - Sudair, Jilh (Gulailah) and Minjur (Figure 15). The Sudair Formation is composed of, mixed carbonate and terrigenous limestones, deposited as three cycles: the lower cycle is formed by limestones interbedded with terrigenous mudstones and minor dolomites, deposited in a shallow-marine setting under variable energy conditions; the middle cycle is dominated by anhydritic dolomitic mudstones, deposited in a supra- to sub-tidal setting; and the upper cycle is composed of a shallow-marine/sabkha facies, consisting mainly of interbedded terrigenous mudstones and dolomite, with minor oolitic-pelloidal packstone/grainstone.

The Jilh (Gulailah) Formation consists predominantly of a sequence of anhydritic dolomite, mudstones and fine terrigenoclastic sediments, with minor intraclastic wackestones and oolitic, pelloidal packstone/grainstones. The formation reflects a continuation of the Sudair sabkha, and the presence of terrigenous sediments, indicates deposition under the sabkha conditions, which bordered a very restricted basin. Minor bioclastic and intraclastic sediments, represent small incursions of more normal marine conditions.

The Minjur Formation is characterised by three coarsening-upward cycles. The lower cycle consists of interbedded argillaceous, quartz sandstones and mudstones with thin coal seams near the base; the middle cycle is composed of interbedded shales and sandstones; and the upper cycle consists of thin sands and argillaceous/dolomitic limestones. The formation was deposited in a fluvio-deltaic setting, and the coarsening upward character of the cycles, represents progradation of delta lobes into interdistributary bay areas. The presence of coal horizons reflects a humid continental/ marginal-marine setting.

C. Jurassic

At the end of the Triassic, there was a relative drop in sea-level, caused either by eustatic sea-level lowering or basement uplift. This resulted in some areas in widespread progradation of fluvial and coastline clastics, and in other areas of basin erosion or non-deposition. Two formations were deposited in the Early Jurassic, the lower one being the Marrat Formation of onshore areas. There is no evidence for this formation in offshore Abu Dhabi and Dubai, due either to tectonic uplift preventing deposition, or alternatively because this formation was eroded. The Marrat Formation is composed of a mixture of terrigenous clastics and carbonates, and is divided into: a lower unit, consisting of interbedded bioclastic packstone/wackestones, intraclastic-peloidal and oolitic packstone/ grainstones, very fine dolomitic lime mudstones, and quartzose sandstones and silty claystones, and an upper unit, consisting of three facies - the middle facies is composed of a complex, mixed terrigeno-clastic-carbonate sequence of mudstones and dolomitic quartzose sandstone, while the lower and upper facies are mainly dolomitic oolitic grainstones, micritic sandstones and sandy limestones. The Marrat Formation represents a regressive sedimentary sequence, deposited in a marginal-marine setting. The lower unit represents an offshore facies, and was deposited under variable energy conditions; the upper unit was probably deposited on a flood plain and in a tidalflat setting.

The second formation of the Lower Jurassic is the Hamlah Formation. In its lower part, it consists of peloidal-molluscan wackestones, overlain by molluscan wackestones and packstones, which are interbedded with bioclastic lime mudstones. These are followed by highly bioturbated, coarser molluscan packstones. The depositional setting suggested is a near-shore marine environment, while the bioturbated limestone facies with marine fauna, suggests deposition under quiet-water but well-oxygenated conditions. In the Middle Jurassic, after the development of considerable uniformity over an extensive area, normal marine shelf carbonate sedimentation was established. The Middle Jurassic is divided into two- the Izhara and the Araej Formations as shown in Figure (15).

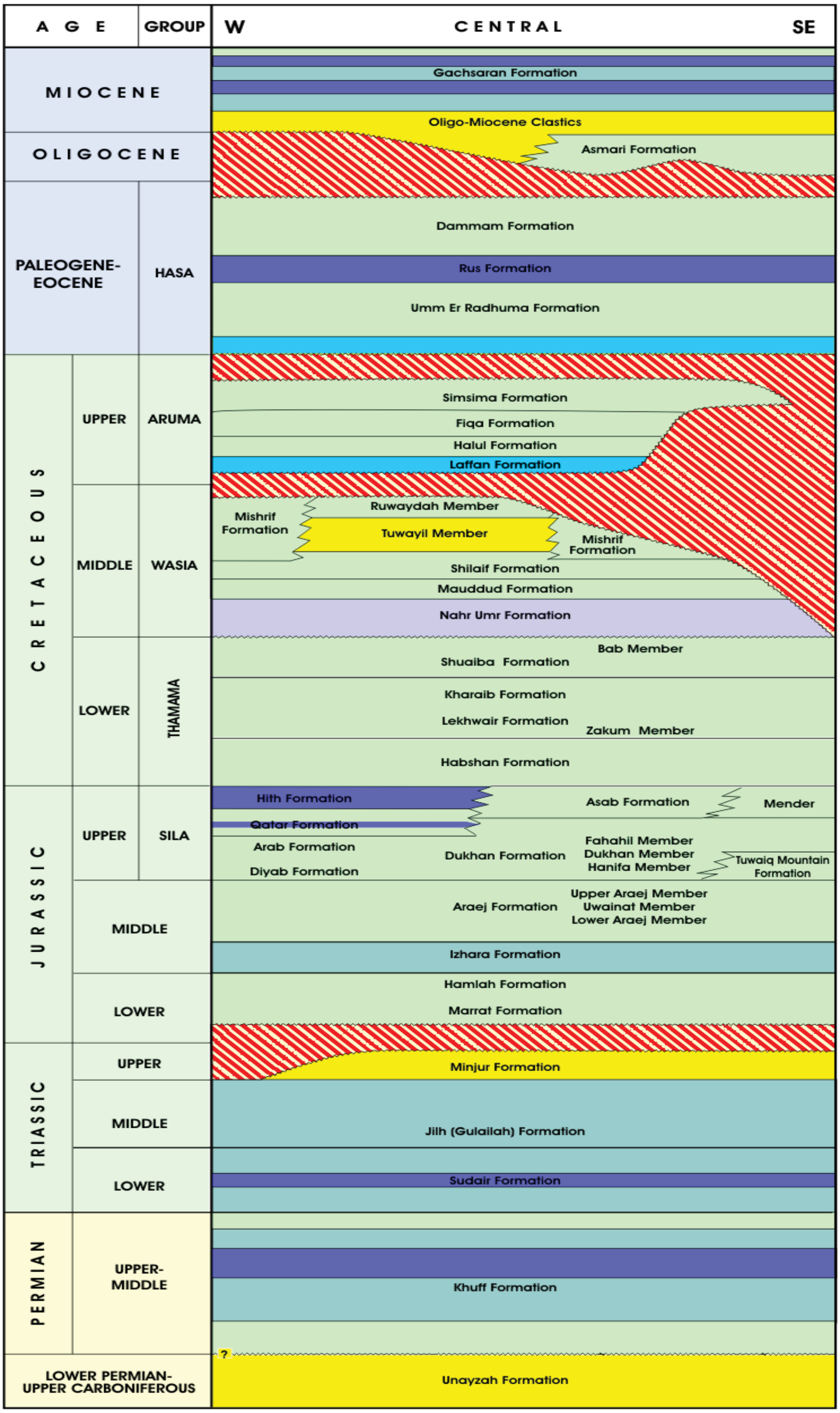


Figure 15: Subsurface lithostratigraphic chart of Abu Dhabi Emirate.

The Izhara Formation is largely composed of, argillaceous lime mudstones with some bioclastic peloidal packstones, grainstones and partly dolomitised, and quartz silt-rich bioclastic lime mudstones. The formation was deposited in quiet-water shelf settings, as suggested by the argillaceous lime mudstones. Minor high-energy fluctuations in the depositional regime occurred, as evidenced by the grain-supported sediments.

The Araej Formation is split into three members. The Lower Araej Member is composed of, bioclastic-intraclastic and peloidal lime mudstones to packstones and minor grainstones, and contains significant amounts of clay and pyrite. The Uwainat Member consists of four different facies: peloidal packstones grading to mudstones; intraclastic wackestones and packstones; mottled, bioclastic lime mudstones grading into bioclastic - intraclastic packstones; and bioclastic, peloidal packstones and grainstones. The Upper Araej Member marks the final stage of Araej sedimentation, and is characterized by dense and argillaceous lime mudstones in the lower part, and by bioclastic-peloidal packstones and oolitic grainstones, containing sparse bivalve fragments, foraminifera, and echinoderm and molluscan debris, in the upper part.

The Araej Formation represents the continuation of a quiet-water marine shelf setting. Intraclasts and peloidal grains suggest higher-energy conditions, while the sections corresponding to muddy sediments suggest a slightly deeper, lower-energy setting. The Late Jurassic carbonate platform became differentiated into broad shelves, with kerogen-rich intrashelf basins, that formed in response to the combination of a eustatic sea-level rise, epeirogenic downwarp of parts of the cratonal area, and accompanying marine flooding (Alsharhan and Kendall, 1986). Patterns of regional sedimentation indicate a gradual transition from deep-water conditions, grading through shallow to very shallow-water conditions.

The first formation of the Upper Jurassic which rests unconformably over the Upper Araej Member, in the onshore area is the Tuwaiq Mountain Formation, which consists of dense bioclastic lime mudstones in its lower part, grading to peloidal, bioclastic packstones, to well-sorted oolitic packstones and grainstones, and ending with coarsely-crystalline euhedral dolomite replacing lime mudstones. The formation represents a regressive sequence of marine shelf limestones. The lower part collected in response to a continuation of the quiet-water, low to moderate-energy, shallow, sub-tidal setting. It gave way to a moderate to high-energy shoal environment, and ended with a regressive phase of emergent (sabkha) conditions.

The Dukhan Formation has been recognized throughout the onshore areas, and differs in lithology and thickness from west to east. It consists of three members - in ascending order, the Hanifa, Dukhan and Fahahil. In western areas, the Hanifa member is composed of dense lime mudstones, interbedded with calcareous shales; towards the SE areas, it becomes an oolitic packstone-grainstone, containing streaks of chalky lime mudstones. The depositional setting ranges from an open-shelf to a near-shore shoal setting. In the western areas, the Dukhan Member overlies the Hanifa Member, and is composed of dense, argillaceous, slightly dolomitic lime mudstones with streaks of shales. In the SE, it is divided into an upper unit, composed mainly of packstone to grainstones, (while some parts of the section contain slightly chalky lime mudstones with sucrosic dolomites), and a lower unit, which is a dense, mainly aphanitic, microcrystalline lime mudstone with anhydrite and dolomite. The member was deposited in shallow lagoonal and tidal flats.

The Fahahil Member is not recognized in wells drilled in SE Abu Dhabi, and this could be due to a minor unconformity, which is either erosional or non-depositional in this region. The member has been recognized in western onshore areas, as a gross lithology of crystalline aphanitic lime mudstone, that grades upward to wackestones and packstones containing dolomite and nodules of anhydrite. The depositional setting is thought to have been shallow-marine and sub- to supra-tidal.

The Qatar Formation (in onshore areas) which overlies the Dukhan Formation, is best developed and most easily recognized in the western areas. In some wells, the Qatar and the overlying Hith Formations, are difficult to separate with any degree of confidence. These two formations grade into each other laterally, and there is a complex change in Lithology, reflecting changing depositional settings, that pass eastward to Asab Oolite or Mender Glauconite. The Qatar Formation is composed mainly of dense, dolomitic lime mudstones, interbedded with anhydrite and dolomites. Dolostone horizons are common, and are believed to have been deposited in extremely shallow to intertidal conditions. Dolostones are either fine-grained and tight, or medium to coarse-grained, sucrosic and porous - this relationship between these two types is probably related to subsequent diagenetic changes. Laminated and/or brecciated lime mudstones are sometimes associated with the dolostones, and correspond to variants of the same tidal-flat setting. Fossiliferous wackestones containing common ostracods are also found.

The Asab Oolite consists mainly of dolomitic lime mudstones, that grade upwards into oolitic grainstones and peloidal-bioclastic wackestone- packstones. This formation represents oolitic bars (shoal lime sand), that corresponds to the open-marine edge of a very shallow platform. The coated grains found in some parts of the section, correspond to more protected conditions with lower energy. The Mender Glauconitic Limestone is developed in extreme SE areas (Mender area), and is composed mainly of bioturbated-bioclastic lime mudstones, and rounded glauconite grains of fine sand size, that grade upwards into bioclastic-peloidal packstones and wackestones with some glauconite. The depositional setting was a deeper, offshore, low-energy area in the lower part, that graded upwards into a shallower, higher-energy environment.

Early in the Upper Jurassic, active subsidence of western areas, resulted in the development of intrashelf basinal sediments, that consisted largely of argillaceous lime mudstones and wackestones, constituting the Diyab Formation in offshore areas, (which is time-equivalent to the Dukhan Formation); while in the east, a cleaner limestone facies, (clean, neritic dolomites and dolomitic limestone) was deposited. In late Upper Jurassic time, the climate became more arid, and a cyclic deposition of carbonates and evaporites prevailed. This was followed by a dominantly anhydritic phase in sedimentation (Murris, 1980; Alsharhan and Nairn, 1997).

The Arab Formation is conformably overlies the Diyab Formation, and conformably underlies the Hith Formation. Based on lithology, the formation is divided into four zones - from top to bottom A, B, C and D. The Arab A, B and C are mainly composed of alternating anhydrite and carbonates, (predominantly dolomites and partly limestones). The Arab D is mainly composed of carbonates, which are predominantly limestones, partly dolomites and occasionally anhydrites. The Arab D was deposited in a marginal-marine shelf setting, at relatively shallow water depth. The very rare occurrence of anhydrite in the Arab D, is interpreted as being related to rapid falls in the relative sea- level, changing the sedimentary environment, over short periods of time, to a peritidal setting favouring sabkha evaporites. The Arab A, B and C were deposited in a peritidal depositional setting, over a relatively wide sabkha flat. Provided that the solubility product of the anhydrite exceeds that of marine waters, the anhydrite could have been deposited on the gently ramped and sloping epeiric sea floor without the presence of barriers or a peritidal environment. However, the presence of nodular anhydrite and algal stromatolites supports a peritidal depositional setting (Alsharhan and Whittle, 1994).

In Tithonian time, the climate became more arid, fostering extensive evaporite deposition in a sabkha over the shallow platform (Murris, 1980). The thick anhydrite section of the Hith Formation, represents the final regressive supratidal stage, of the major depositional cycle. In western areas, the Hith consists principally of anhydrite with subordinate dolomite. In the Zakum and Bab fields, the Hith is represented by a thin anhydrite at the top, which is underlain by anhydritic dolomite. East of Zakum, the anhydrite disappears, and the Hith equivalent consists of dolomites, which are partly anhydritic of lagoonal origin, and in some areas, such as along the Asab-Mubarraz fields trends, oolitic limestones of high energy shoal setting were developed.

D. Cretaceous

The Cretaceous of Abu Dhabi, as well as that of the Arabian Peninsula, is divided by regional unconformities into three major units: the Lower Cretaceous Thamama Group (Berriasian-Aptian); the Middle Cretaceous Wasia Group (Late Aptian - Cenomanian); and the Upper Cretaceous Aruma Group (Coniacian - Maestrichtian). The Lower Cretaceous is composed of thick carbonate sequence, and is the product of extensive flooding of the Arabian Peninsula. Thus, over a time-span of nearly 30 MM yrs, carbonate shelf to shallow-basinal conditions were established. The Lower Cretaceous (Thamama Group) is split into four formations which, in ascending order, are the Habshan, Lekhwair, Kharaib and Shuaiba.

The Habshan Formation formed updip on a vast carbonate ramp developed during the initial Cretaceous flooding of the stable cratonal platform, and embodies the progradation over, and subsequent filling of, the old Middle to Late Jurassic cratonal margin depression (Hassan et al., 1975; Alsharhan and Nairn, 1986). In eastern areas, the Habshan Formation contains a pelleted, sometimes intraclastic, and less commonly oolitic limestone at the base, and this is followed by a sequence of mainly lime mudstone and wackestone, with very limited occurrences of grain-supported limestone, accompanied by varying proportions of dolomite and dolomitic limestones. In the central onshore area, the formation is made up of lime mudstone, which is slightly argillaceous and contains minor interbeds of pelleted, dolomitic packstone and wackestones with minor shale; in the onshore area, the formation consists of cyclic alternations of chalky, partly dolomitic, lime mudstones and wackestones, minor intraclasts, and peloidal packstone, while at a lower horizon, a thick bed of peloidal, bioclastic grainstone with anhydrite exists (Hassan et al., 1975; Alsharhan and Nairn, 1986). The depositional setting of the Habshan Formation ranges from bank margin shoal to a more protected near-shore setting, which alternates with lagoonal supra-tidal bank margin deposits.

During deposition of the Lekhwair Formation, minor tectonic pulses created a series of minor transgressions and regressions. The control of carbonate production could involve an interaction, between eustatic sea-level fluctuations and fluctuations in climate. Shallow, but below wave-base level, cyclic sedimentation took place in the area. Each cycle is composed of dense argillaceous lime mudstones-wackestones, that grade upwards into peloidal packstone-grainstones. The Lekhwair Formation can be characterized as alternating cycles of shallow, sub-tidal turbulent-water grain-rich limestones, with somewhat deeper-water sub-tidal mud-rich carbonates. The persistence of these cycles, and their extensive development throughout the stratigraphic section, suggest that the depositional surface on the shallow carbonate ramp was extremely flat.

The Kharaib Formation is composed of four sedimentary cycles; the porous, grain-supported limestones represent regressive phases, whereas the tight limestone units (mud -supported) represent marine transgressions. The porous units were laid down on very shallow, epeiric shelf seas above wave-base level. The dense units in between were deposited in an open, slightly deep-marine shelf setting. These carbonate cycles may have occurred, while there were substantial fluctuations in the rate of production, and deposition of carbonate sediments on an extremely low-relief depositional surface.

The Shuaiba Formation is the terminal event in the deposition of the Thamama Group, and records the differentiation of the stable craton in early Aptian time, into an intrashelf basin surrounded by shallow-shelf carbonate facies. The Shuaiba intrashelf basinal facies, occupies a depression in the stable craton, which was most likely formed by differential rates of subsidence due to rapid crustal cooling. The Shuaiba basinal facies has been termed the Bab Member (Alsharhan, 1985), and consists mainly of well-bedded, gray to dark gray-brown dense and argillaceous lime mudstones and wackestones, with a few gray shales and interbeds with deep-water marine fauna. On the shelf margin of this basin, calcareous algae and foraminifera with biohermal rudists, accumulated as bioclastic peloidal packstone-grainstones, with subordinate lime mudstones and wackestones. This formation forms the most prolific reservoirs in the area (e.g. the Bu Hasa oilfleld).

The mid-Cretaceous section is bounded by unconformities above and below known as the Wasia Group. The base is fixed where the shales of the Nahr Umr Formation overlie the Shuaiba; at the top, the shales of the Laffan Formation of the Aruma Group overlie the limestones of the Mishrif Formation or its equivalent. The group was deposited over a time span of 21 MM yrs (late Aptian to the latest Cenomanian), and represents an upward change from shallow-shelf clastics, to shallow-shelf carbonates. The Wasia Group is divided into four formations - in ascending order, the Nahr Umr, Mauddud, Shilaif (Khatiyah) and Mishrif Formations (Tuwayil and Ruwayda members) (Alsharhan and Nairn, 1988). The Nahr Umr Formation consists of gray to gray-green shales and mudstone with a few thin lenses of impure carbonates, with abundant Orbitolina. This grade to tan and yellowish-gray shales and end as interbedded red, brown fairly hard and splintery shales. The formation was deposited on a shallow shelf in a sub-tidal setting. The Mauddud Formation is composed of relatively uniform, shallow, shelfal skeletal and peloidal packstones and wackestones, and contains rudist fragments locally. It accumulated during a widespread transgression on a shallow, carbonate marine shelf.

In upper Albian time, the combination of eustatic sea-level rise, and mild differential subsidence over parts of the craton, led to establishment of open-sea conditions in the Shilaif-Khatiyah intrashelf basin. This intrashelf basin persisted through the mid-Cretaceous, but was drained completely in the Turonian. The Shilaif-Khatiyah Formation is composed of silty to very fine sand-grade sized, organic-rich, laminated lime mudstones, bioclastic peloidal packstones and wackestones, containing abundant Oligostegina. Benthonic foraminifera and molluscs are sparse, while planktonic foraminifera and calcareous nanofossils are abundant.

The Mishrif Formation was deposited on the edges of the intrashelf basin, and is characterised by mollusc-fragment grainstones and packstones, rudist and algae grainstones and boundstones, and muddy bioclastic miliolid limestones. The sediments of the Mishrif were initiated as a rimmed, carbonate shelf with a broad shelf lagoon to the west, separated from the relatively-deep Shilaif-Khatiyah intrashelf basin to the east, by a discontinuous marginal shoal. The carbonate shelf prograded basinward as a series of cycles. The western shelf area of Abu Dhabi deepened slightly into a more open-shelf sedimentary regime, as being characterised by two units: the lower is mainly clastic Tuwayil Member with a western source, representing the distal extension of the Ahmadi Formation of Qatar; the upper unit is composed mainly of deep- water limestone, and is known as the Ruwayda Member. The Tuwayil member is composed of gray to dark gray lignitic shales, that are interbedded with fine-grained sandstones, siltstones and mudstones, which are regarded as having been deposited as a prodeltaic wedge. The Ruwayda Member consists mainly of light gray, argillaceous, chalky, pelagic, fine to siltgrade sized lime mudstones and wackestones, forming the final basinal depositional phase of the Cenomanian in Abu

Dhabi (Azzam, 1995).

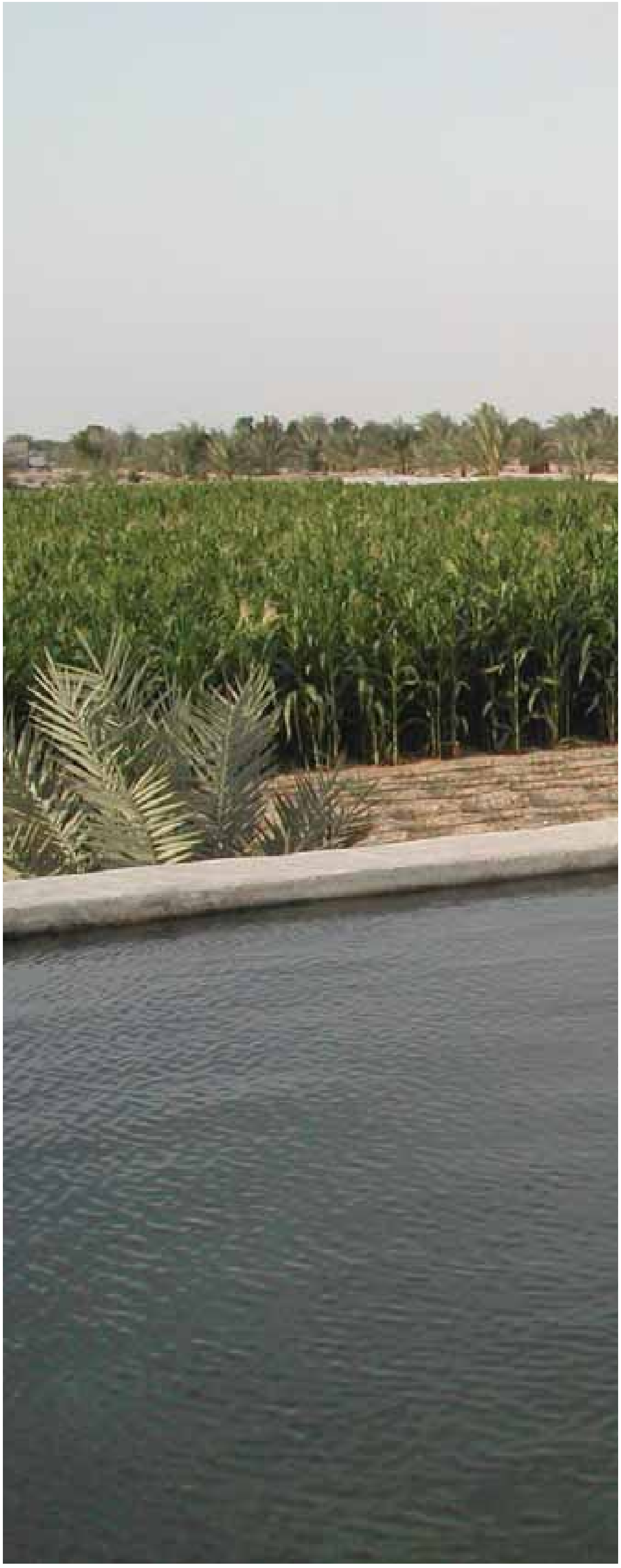
The Upper Cretaceous section is also bounded by unconformities above and below known as the Aruma Group. The earliest Upper Cretaceous sedimentation accompanied a transgression that probably began in the late Turonian, spreading to cover most of the Gulf area by Coniacian time. This event is marked by the shales and neritic marls of the Laffan Formation. During the Santonian, the neritic shelf carbonates of the Halul Formation were deposited. The Laffan and Halul couplet form one transgressive-regressive cycle within the Aruma megacycle. Deep subsequent subsidence resulted in the lower Campanian transgression, and the deep-water basinal marls, argillaceous limestones and shales of the Fiqa Formation. During Maestrichtian time, a widespread regression occurred, and the neritic shelf limestones and dolomites of the Simsima Formation were deposited over most of Abu Dhabi.

The Laffan Formation consists mainly of shales with minor argillaceous limestones. The initial deposits of the Laffan were of deltaic origin, and were sourced to the east, but the bulk of the formation was laid down in an open-marine shelf setting. The Halul Formation consists of interbedded calcareous shales and mudstones, of a deeper-shelf environment, which grade upward to skeletal and peloidal wackestone-packstones, with subordinate lime mudstones, that were deposited in a shallow-water setting. The Fiqa Formation consists of argillaceous limestones and marly shales, with a deep-marine fauna (calcispheres and planktonic foraminifera), suggesting deposition on a deep shelf. The Simsima Formation consists of peloidal, bioclastic packstones and wackestones and dolomitec limestones with coral and rudist build-ups which accumulated on a mixed, shallow, sub-tidal to tidal-flat setting (Alsharhan, 1989).

E. Tertiary

The end of the Cretaceous is marked by a regional unconformity that forms the boundary between Upper Cretaceous and Tertiary formations in Abu Dhabi. The Lower Tertiary in Abu Dhabi is known as the Hasa Group, and consists of three formations - the Umm Er Radhuma, the Rus and the Dammam. The Umm Er Radhuma Formation (Paleocene-Early Eocene), is represented by a thin basal bed of shales, capped by bioclastic packstone-wackestones, argillaceous limestone and dolomitic limestone, which were deposited in a shallow-marine setting. In the lower Eocene, a wide evaporitic platform is represented by a sequence of restricted-marine evaporites and dolomites - the Rus Formation. In the middle Eocene, open-marine shelf conditions led to the thick development of nummulitic shallow-water carbonates - the Dammam Formation, which is composed of calcareous shales and argillaceous limestones that grade upwards to peloidal, bioclastic packstone-grainstone and dolomites of tidal-flat origin. During Upper Eocene and Lower Oligocene, uplift and erosion affected most of the Arabian Peninsula. This uplift was most effective in Qatar and western Abu Dhabi. A transgressive phase then followed, with the deposition in extreme eastern Abu Dhabi, of bioclastic dolomitic limestone with thin interbeds of marls and calcareous lime mudstone, of shallow shoal and lagoonal origin (the Oligocene Asmari Formation). This was followed by the Gachsaran (Lower Fars) Formation, which consists of three units: a lower unit of mainly anhydrite with quantities of minor dolomite and terrigenous clastics; a middle unit of dolomite and limestone; and an upper unit of interbedded anhydrites, shales, marls and limestones. Further uplift and erosion occurred in upper Miocene - Pliocene times, over most of Abu Dhabi, and the adjacent area in response to the Alpine Orogeny (Alsharhan and Nairn, 1995). The Neogene sediments of Abu Dhabi consists of Late Miocene Baynunah Formation (quartz sandstone, siltstone, marl, paleosols and conglomerates). Followed by Late Pliocene-Pleistocene consists of polymictic lag gravels, moderately cemented sandstones and siltstones; very fine to medium-grained well-cemented calcareous sandstones, and mixed unconsolidated carbonate and siliciclastic sands.

5 Water Resources



The water resources of Abu Dhabi can be grouped into two categories: (1) Conventional resources consisting of groundwater, surface runoff (wadi flow), falajes and springs; (2) Non-conventional resources consisting of desalinated water and treated wastewater.

5.1 Conventional Resources

5.1.1 Springs and Falajes

a) Ain Al Faydah Spring

Ain Al Faydah (also known as Bu Sukhnah) spring lies approximately 15 km south of Al-Ain city, and 4 km west of the margin of Jebel Hafit. It forms broad shallow depression situated on the gently sloping gravel and sand plain of Jebel Hafit on the east and sand dunes on the west. The structure is this spring is simple, and there are no major faults, however, there are numerous fractures and veins could provide channel ways for groundwater (Hunting, 1979). Ain Al Faydah spring tend to discharge from local and intermediate groundwater-flow systems. The water in this spring thermally mineralized water with therapeutic value, which have been utilized as recreational and touristic sites. The spring issues from Middle Eocene limestones, clays and claystones with conglomeritic limestones, and Miocene gypsum and clay layers through thin loose Quaternary sediments. Records of spring discharge for the period 1984-1991 indicate that the Ain Al Faydah spring has good discharge (2.50x106 m^3/yr) as shown in Table (4).

There are black organic deposits with 21 ppm uranium, along the joints and bedding plains, of some calcareous rocks of Jebel Hafit (Hunting, 1979). The lack of these deposits in other layers is attributed to leaching by water which, discharges into the Ain Al Faydah spring. The heat associated with radioactive decay of uranium, may contribute to the rise in the water temperature of the spring. Water circulation in the Ain Al Faydah spring is slow, and independent of rainfall and water table fluctuation. Water chemistry variation results from slow circulation, and is insensitive to rainfall and water-table fluctuations as shown in Figure (16). Sodium-ion concentration reached 1,600 mg/l and Sodium Adsorption Ratio about 17.4%. The Total Dissolved Solids (TDS) content of water has increased from 1968 to the present by 50%. This increase is mainly related to intensive groundwater extraction in recharge areas and low rainfall during the last few years. However, the increase in Total Dissolved Solids content, from 5,500 mg/l in 1977 to 10,228 mg/l in 1994, occurred at a time of increasing discharge, from 0.96x106 m^3/yr in 1984 to 2.50x106 m^3/yr in 1991 (Alsharhan et al., 2001). The dissolution of Miocene evaporite deposits through which the spring water moves, may contribute to the high-salinity water of the spring.

b) Al-Ain Falajes

Falajes in Arabic means, the division of an ownership into shares, among those who have water rights. In the Emirate of Abu Dhabi all the falajes are concentrated in Al-Ain region. The falaj system has provided communities with water, for irrigation and domestic purposes, for the last 1,500 to 2,000 years. These systems raise groundwater to the surface, without any mechanical device, or costly expenditure of fuel.

Year	Discharge (Mm^3)
1984	0.96
1985	1.10
1986	1.42
1987	1.58
1988	1.51
1989	1.45
1990	1.58
1991	2.50

Table 4: Ain Al Faydah spring discharge (Mm^3/y).

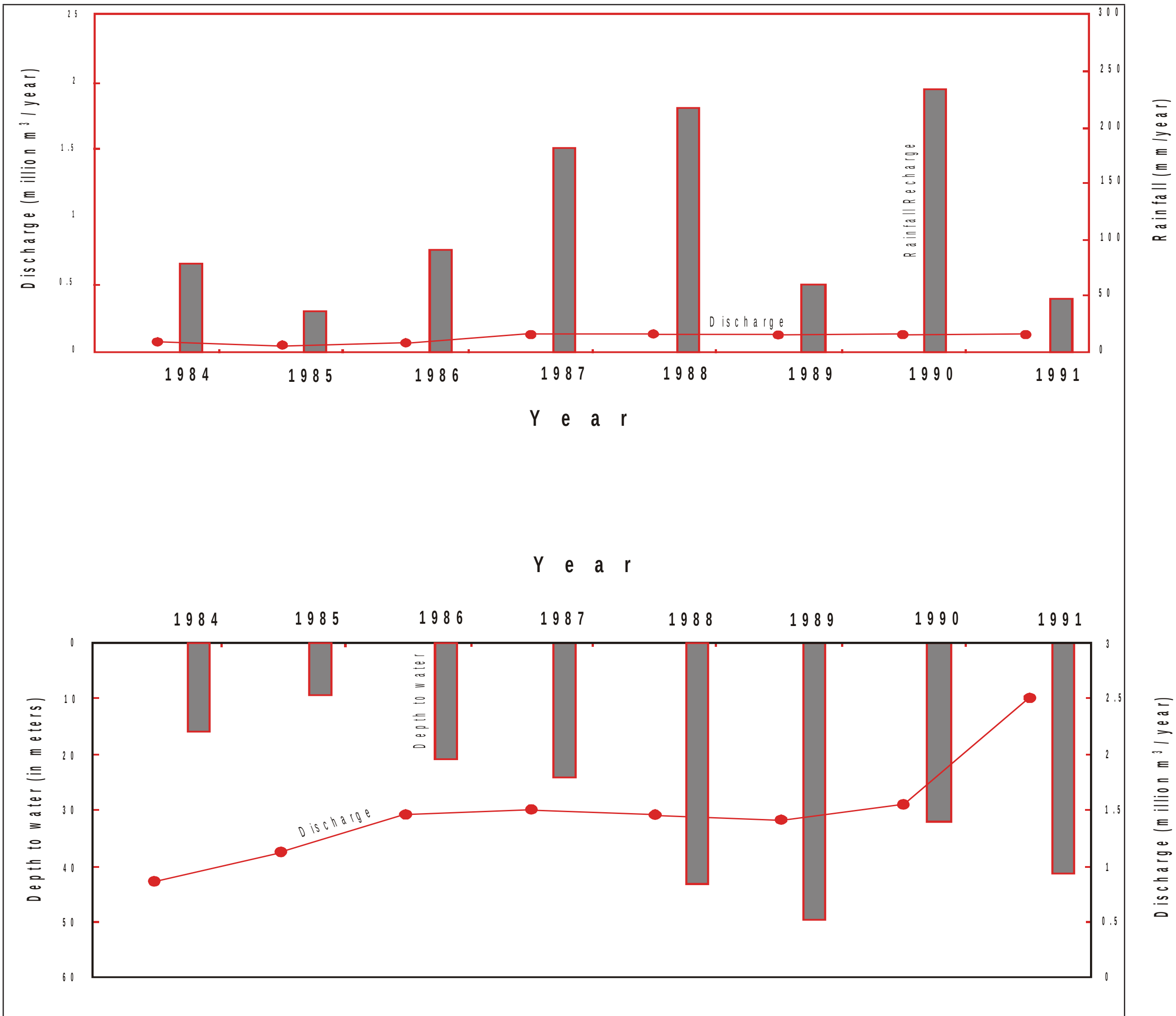


Figure 16: (a) Relationship between discharge-rainfall of the permanent Ain Al Faydha spring in Abu Dhabi Emirate. (b) Relationship between depth-to-water (below ground surface) in local observation wells and discharge of the permanent Ain Al Faydah spring in Abu Dhabi Emirate.

A falaj is defined as a man-made stream, which intercepts the groundwater table, through a single or several wells, at the footslopes of high mountains. It brings water to the surface through a tunnel, which has a slope gentler than the natural hydraulic gradient. As a falaj intersects the ground surface, it splits into several branches (called awamid or the columns).These are narrow, deep, open, and cement-lined small channels which deliver water from the main tunnel of the falaj, to farm lands and palm oases. Falajes vary in length, width, quantity of water they carry, and the nature of the ground, through which they pass. The upper part of the falaj tunnel, below the water-table, serves as an infiltration gallery, and may have several branches to increase flow. The slope of the tunnel is gentle enough to avoid erosion. Prior to construction an expert (Al Basheer or the foresighted), based upon his experience, selects a site for the mother well (Umm al Falaj). As the falaj intersects the ground surface, connecting tunnels are constructed, and aerated through wells spaced at about 10m intervals. The well heads are usually surrounded by a ring of baked clay, and may be covered to prevent flooding, and the influx of debris, and to reduce losses through evaporation (Rizk, 1996; Alsharhan et al., 2001).

At the surface the falaj is split into a number of distributary channels, which deliver water from the main tunnel of the falaj, to the farm lands and palm oases. The main tunnel of the falaj may reach a depth of 30m, but decreases gradually, as the falaj approaches the surface. Vertical shafts are constructed at distance from 5 to 8m. The tunnel is extended by digging horizontally between shafts. Tunnels are chosen in preference to open channels to reduce evaporation losses, especially when the channel would be long (channel lengths range between 3 and 20 km).

The main construction problems concern either the presence of compact rocks, hard to penetrate with hand tools, or soft rocks liable to collapse. More recently modern tools as drill rigs, and electrical power tools, have solved many of these problems of hard rocks. In soft sediment, the tunnel may be lined with tiles, about 1m long by 12-24cm wide, so that many workers may be required, for the construction of a single falaj tunnel. Falajes need periodic maintenance and restoration, which increase discharge, and improve water quality. To do so, three parts has to be dealt with: water collection areas, the tunnel and open channels. The water collection area has to be continuously cleared, to guarantee water flow, from the sides of the tunnel, and monitored to prevent any pollutant, to enter the water of the falaj. Maintaining the tunnel need to restoring the collapse, and failure in lining of the tunnel, which transmits water from the source area to usage area, minimizes water loss through seepage, and increases falaj discharge. To maintain falaj open channels have to be cemented-lined, to minimize water loss though seepage, and covered it to reduce water loss by natural evaporation, especially in summer times.

Although the main water source of these falajes is the shallow groundwater of the Quaternary aquifer, there is a direct relation between the mean annual rainfall and the discharge (Rizk, 1996; Alsharhan, et al., 2001). There are also cycles of about five to seven years during which falajes discharge is above average, which is identical to rainfall cycles of the same time interval. Sir William Halcrow and Partners (1969) identified the major falajes in Al-Ain area that yielded $10.5x10^6$ m^3/yr of good quality water, and calculated their discharge as shown in Table (5). Between 1984 and1991 total discharge ranged between $6.71x10^6$ m^3/yr to $9.21x10^6$ m^3/yr as shown in Table (6).

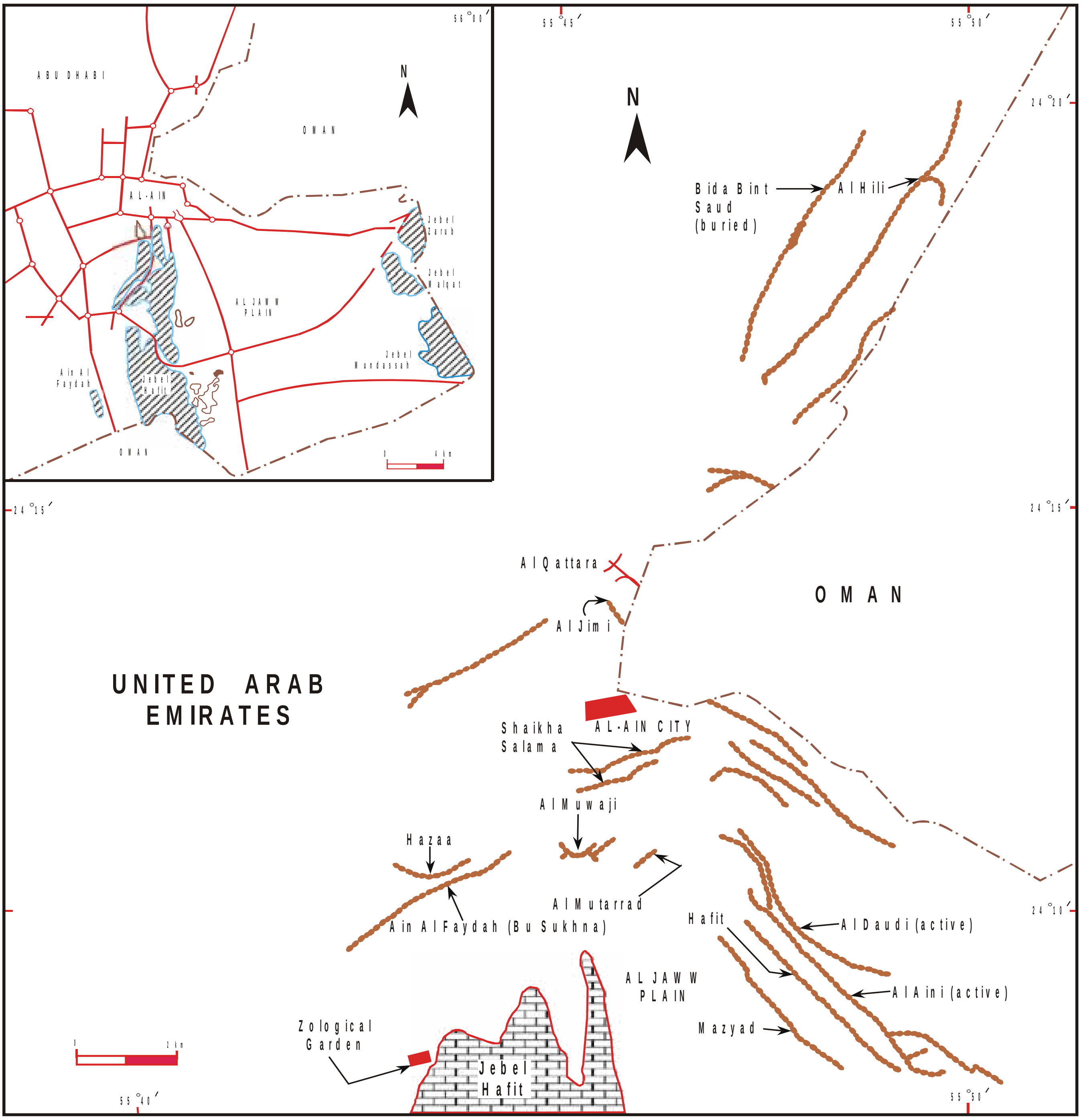


Figure 16b: Map view and a vertical cross section of a falaj

(Modified by Alsharhan et al., 2001 after United Arab Emirates National Atlas, 1993).

Table 5: The discharge (liters per second) of Al-Ain falajes during the period 1964-1968 (Sir William Halcrow and Partners, 1969)

Falajes Name	Discharge (liters per second)							
	Dec. 1964	Nov. 1965	Apr. 1966	June 1966	Dec. 1966	May 1967	Sep. 1967	Jan. 1968
Al Aini	56.6	68.0	51.0	76.5	90.9	130.0	149.0	142.4
Al Daudi	39.6	31.1	39.6	45.3	70.3	48.0	37.3	60.1
Mu' Tarad	42.5	28.3	36.8	53.0	52.2	42.5	76.4	98.0
Al-Jimi	56.6	42.5	56.1	58.1	92.3	55.5	80.2	71.4
Qattarah	28.3	28.3	36.8	32.8	34.5	17.8	26.2	43.7
Al-Hili	39.6	28.3	36.8	32.8	34.5	17.8	26.2	43.7
Muwaiji	11.3	31.1	19.8	20.9	24.9	20.9	22.1	26.1
Total	**274.5**	**257.6**	**271.7**	**319.2**	**401.5**	**326.7**	**430.6**	**484.7**

Table 6: Falajes discharge

Falaj Name	Discharge in million cubic meters per year								Length (m)	Electrical Conduct-ivity	Total Dissolved Solids
	1984	1985	1986	1987	1988	1989	1990	1991			
Mazyad	0.50	0.79	0.63	1.26	1.01	0.95	0.98	0.95	2000	960	624.0
Al Hili	0.85	0.95	0.57	0.44	0.66	0.88	0.97	1.10	4000	750	487.5
Al Daudi	0.63	0.69	0.95	1.50	1.61	1.70	1.77	1.32	5000	520	338.0
Al-Aini	3.66	3.66	1.55	1.77	1.55	1.39	1.42	1.36	6000	520	403.0
Total	**5.64**	**6.09**	**3.70**	**4.97**	**4.83**	**4.92**	**5.14**	**4.73**			

(million cubic meters per year), length (m), electrical conductivity (EC) in micromohs per cubic centimeters at 25o C and the total dissolved solids (TDS) in milligrams per liter (mg/l) during the period 1984-1991 in Al-Ain region.

5.1.2 Surface water

Historically, permanent settlements developed around areas where fresh, drinking water occurred either at or very close to ground level. Means of groundwater development were either aflaj, shallow hand dug wells or wadi diversion/rainfall harvesting structures. Today, the only perennial, natural surface water system in the Emirate is found at Ain Al Fayda, in Al Ain. Wadi flows and surface sabkha ponding are ephemeral and natural phenomena but there are also numerous artificial lakes and ponds, e.g. Al Wathba Wetland Reserve and Mubazarah Lake which serve as areas of recreation, conservation and environmental education.

a) Springs

The strict definition of a spring is a point where groundwater flows out of the ground, and is thus where the aquifer surface meets the ground surface. Depending on how constant the source of the water is, springs can be ephemeral (intermittent), perennial (continuous) or artesian. Whilst numerous springs are found in the other Emirates, Abu Dhabi can only boast one perennial spring, that of Ain bu Sukhanah spring at Ayn Al Fayda (Elschami, 1990), despite often misleading references to other, non–existent springs, e.g. Al Ain Mineral water, Jebel Hafit, etc..

Located 15 km south of Al Ain city, the Ain bu Sukhanah spring produces clear brackish water at a constant temperature of 39.3 ˚C with a flow of around 160 l/s (Terratest, 1974, 1975). The karstic sink out of which the spring emerges was developed in the 1980's as part of Ayn Al Faydah Tourist Resort. The rise of water to surface is brought about by development of true artesian conditions due to the presence of a flow restrictive shallow horizon and deep water – bearing and transmitting horizon that is connected to a high altitude source area. The water is of Calcium -Sodium Chloride type with a salinity of around 5500 mg/l TDS (low brackish), higher salinity than expected due to the springs passage through a Miocene gypsum sequence.

b) Wadi Flows

A wadi is a dry riverbed that only contains water during times of heavy rain and subsequent run-off. The gravel and boulder filled channels, in the case of Abu Dhabi Emirate, all emanate in neighbouring Sultanate of Oman where they cut through and flow out from the Al Hajar Mountain group onto piedmont plains and alluvial fans before crossing the international boarder into U.A.E. Figure (17) shows a map of the wadi catchments in Oman where the wadis are formed. Here the catchments are often well defined and wadis are steep and often active after heavy rainfall, but by the time they enter the Emirate, topography is generally much flatter and flow velocities are much reduced.

Wadis cross the Oman – Abu Dhabi boarder from twelve main catchments and the total mean annual surface wadi flow entering the Emirate is estimated as 7.6 Mm^3/yr. Sometimes, cross boarder flows are significant and have caused flood damage. In March, 1997, a 55Mm^3/week wadi flow occurred in the Al Fatah/Dank catchments and caused significant flood damage to the town of Al Quaa. Subsequently, a protection bund has been constructed in the town to mitigate any further event. Figure (17) also shows the estimated groundwater through-flow associated with the surface catchments. A mean annual total of 30.9 Mm^3/yr is estimated to enter the Emirate as groundwater throughflow, the largest contribution occurring within Wadi Dank catchment, benefiting the area around Al Quaa.

Rizk et al (1998b) studied the surface runoff and flood potential of the major drainage basins within the Emirate. Rainfall is mainly in the months of February and March and there are 4-5 year cycles of above average rainfall. Figure (18) shows the internal basins, located both adjoining the Oman mountains and also surrounding Jebel Hafit with relief varying from 300-800 m and 100-800 m respectively. The basins have high to very low risks of flooding and the study showed that the minimum rainfall required to produce runoff for the Oman and Jebel Hafit basins is 75 mm/yr and 90 mm/yr respectively, for the period 1981-1992. However, a high intensity, single event of around 30mm is more than enough to produce significant runoff in any catchment. The highest risks of flash flooding occur in wadis Shik, Sidr and Ain Al Faydah and the lowest risk in wadis Khuqayrah and Muraykhat. The average annual runoff depth for the study period 1981-1990 ranges from 5 mm to 20 mm and the percentage of rainfall generating runoff averages about 7 %, with a range form 3 % (Jebel Hafit basins) to 18 % (Oman mountain basins). The predicted long term annual average runoff for the former basins is 1.96 Mm^3/yr and for the latter, 13.78 Mm^3/yr.

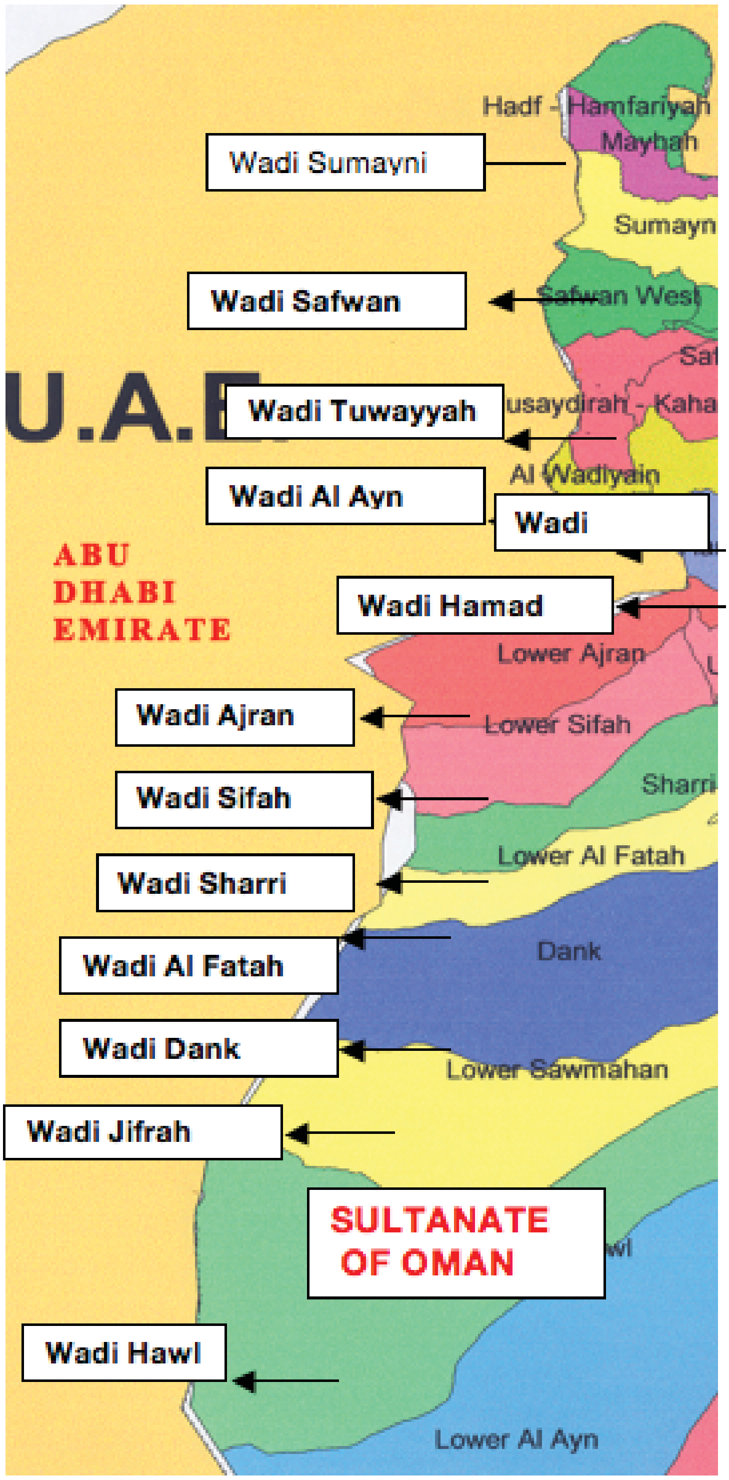


Figure 17: Major wadi catchments entering Abu Dhabi Emirate from Sultanate of Oman (Adapted from MWR, 1999).

Catchment Flow to UAE–Abu Dhabi Emirate (Mm^3/yr)

Catchment	Surface	Groundwater
Sumayni	0.2	1.4
Safwan	1.48	2.6
Musaydirah – Kahal	1.4	1.9
Al Wadiyain	0.6	4.7
Hamad	1.9	1.1
Ajran	0.0	1.0
Sifah	0.0	2.6
Sharri	0.0	2.4
Al Fatah	2.1	2.0
Dank	0.0	7.0
Sawmahan	0.0	2.6
Al Haw	0.0	1.6

TOTAL 7.6 Mm^3/yr Wadi Flow
30.9Mm^3/yr Groundwater Throughflow

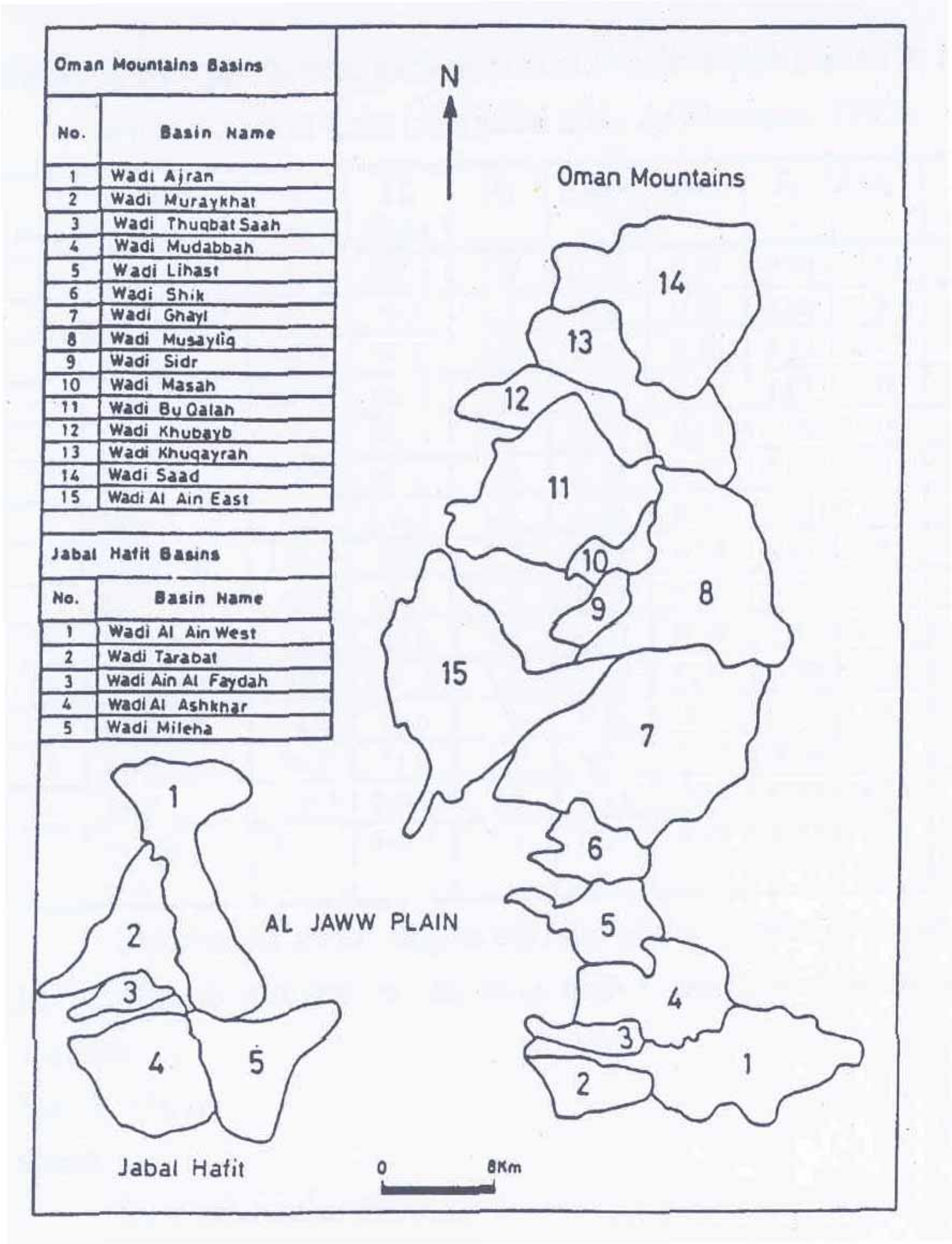


Figure 18: Internal drainage basins within Abu Dhabi Emirate (Rizk et al, 1998b).

c) Sabkhas

These surface deposits occur in Abu Dhabi Emirate as extensive inter-tidal and inland saline flats, known locally as sabkhas; a general term in the area to describe saline and hyper-saline desert flats devoid of all vegetation (Barth and Boer, 2002). Sabkha occurs in groundwater discharge zones, either along the coastal plain and the inland Sabkah Matti (Evans & Kirkham, 2002) or within interdunal areas in the south of the Emirate, close to the boarders with Oman and Saudi Arabia. The coastal and inland sabkhas occupy an area of about 13,500 km², or around 20% of the total landmass of the Emirate. The sabkha plains are dry for the most part of the year, but contain surface water when strong onshore winds drive seawater inland, after periods of heavy rainfall and also in winter when groundwater levels rise within the coastal belt. The hydrogeology of the sabkha has been described in detail by Sanford and Wood (2001) and sabkhas as aquifers will be described below in section "Unconsolidated Aquifers". Sabkhas are classified as coastal, supralittoral or inland. There are also three subclasses, namely, permanently wet, periodically flooded and permanently dry. The first contains lakes and ponds where the groundwater table is always within a few centimeters of the ground surface and the sabkha is permanently wet. The second subclass refers to ephemeral surface water brought about by heavy rains or wind blown tides. The latter is permanently dry.

d) Artificial lakes and ponds

These have been created in the Emirate mostly for recreational and conservation purposes. Occupying an area of about 132 hectares (3.5 x 1.5 km) and located about 40 km south-east of Abu Dhabi city as shown in Figure (19), the largest artificial lake is found at Al Wathba Wetland Reserve (ERWDA, 2001a) and is the first protected area declared by Decree in the Emirate of Abu Dhabi. Managed by EAD since 1998, the site shows great biodiversity, despite a typical lake salinity of 180,000 mg/l TDS (reaching max 230,000 mg/l TDS). The Groundwater – Surface water relationships have been investigated by exploration and monitoring by ERWDA (2003c, 2004e).

Other significant lakes and ponds occur at Shahama (Javed, 2003), Khazna, Mubazzarah (Resources en Eaux Minerales, 2004), Ain Al Fayda and Ajban (Javed, 2002). The Shahama saline body (52,000 mg/l to 119,000 mg/l TDS) is 37 ha in size and is a dredged sabkha with water contribution from runoff and groundwater. The Khazna and Al Ajban (1 ha – located 24° 62983'N, 54° 79265'E) surface water bodies are also formed by runoff from excess drainage from irrigation of nearby farms and forestry. At Al Mubazzara, Jebel Hafit, a brackish, artificial lake has been constructed as a recreation feature to collect pumped water from a series of groundwater wells which tap geo-thermal waters of potential therapeutic value. The lakes at Ain Al Faydah are artificially excavated and are supplied with brackish water from the nearby Ain bu Sukhanah spring.

Figure 19: Location of Al Wathba wetland reserve.

5.1.3 Surface water development

Development of surface water is achieved through constructing dams and other diversion/retention structures. Abu Dhabi topography is not generally suitable for the construction of recharge dams. In fact, only one recharge structure, a diversion bund with several downstream recharge basins, exists in the Emirate at Al Shwaib and succeeds in diverting Wadi Sumeni into a series of recharge basins as it enters Abu Dhabi territory and has a combined storage capacity of 31.5 Mm^3. The main beneficiary of the enhanced recharge is agriculture; numerous farms exist immediately south of the diversion structure. Details of the wadi diversion structure are given in Table (7). Figure (20) shows the main diversion channel.

The several mountainous terrains of the Northern Emirates is far more suitable for the construction of dams; 114 dams have been constructed with a combined capacity of greater than 114 Mm^3. Other surface water management methods practiced include wadi diversion and bunding, sabkha pond bunding and control, development of artificial wetlands e.g. Al Wathba, excavation of artificial lakes for beautification e.g. Mubazzarah, Ruwais Town centre and lakes development associated with recreational activities, e.g. Abu Dhabi Golf Club, Ain Al Fayda.

Table 7: Details of Shwaib diversion structure.

Project Item	Dimensions	Capacity, Mm^3
Shwaib Dam	Length 3000 m, height 11m	**5**
Approach Channel	Length 3600 m, width 150 m	**5.5**
Shwaib Reservoirs	Seven reservoirs	**21**
Total Shwaib Dam and Reservoirs project		**31.5**

Source: Al Ain Municipality, Road & Dams Department

Figure 20: Shwaib – wadi diversion structure - main channel.

5.1.4 Groundwater

Total groundwater reserves for the Emirate have been assessed by two independent studies. The first one was jointly conducted by the National Drilling Company (NDC) and the US Geological Survey (USGS) under the auspices of the Groundwater Research Program. The second study was conducted jointly by GTZ/ADNOC under the joint Groundwater Assessment Project (GTZ 2004). Both projects assessed current groundwater reserves however the used methods differ somewhat. Both have used average saturated thickness and specific yields to estimate stored volumes. The volume of fresh groundwater reserves calculated differs by 8 percent. It is not possible to compare the estimates of brackish groundwater reserves as each study has used different salinity ranges for brackish water. Whereas the USGS study defined brackish groundwater between 1500 mg/l and 15,000 mg/l, the GTZ study used 1500 mg/l to 10,000 mg/l as brackish and 10,000 mg/l to 100,000 mg/l as saline. In this sector paper we have used the groundwater reserves estimated by USGS summarized in Table (8), as brackish water up to 15,000 mg/l is used for forest irrigation.

At the current rates of extraction both fresh and brackish groundwater resources will be exhausted in the next 50 years (USGS 2006). Thus it will be critical to ensure that groundwater resources are managed sustainably and in particular the use of groundwater for irrigated agriculture which is the largest consumer has to be moderated by employing innovative strategies. Some of these strategies will be discussed in this theme whilst others more pertinent to agriculture will be discussed in the agriculture and irrigation theme.

Table 8: Groundwater reserves estimate for the Emirate (after USGS 1996)

Salinity Zone Fresh (<1500 mg/l)	Area (m2x106)	Avg. Saturated Thickness (m)	Average Specific Yield	Volume in Storage (Mm3)
Fresh – Eastern Region	1440	20	0.14	4,000
Fresh – Western Region	2400	26	0.23	14,000
Fresh – Emirate	**3840**			**18,000**
Salinity Zone Brackish (>1500 and <15,000 mg/l)				
Brackish below Fresh Water – Eastern Region	1440	40	0.14	8,000
Brackish below Fresh Water – Western Region	2400	69	0.23	38,000
Brackish – Remaining Areas	29,983	42	0.15	189,000
Brackish - Emirate				**235,000**
Total Fresh and Brackish - Emirate				**253,000**

5.1.5 Unconsolidated Aquifers

These are the most common and productive aquifers and comprise both recent sand dunes and alluvial deposits of varying age. Figure (21) shows their respective distributions. Collectively, the deposits comprise the surficial aquifers of Abu Dhabi Emirate or alternatively, the shallow, unconfined aquifer. The following units of the shallow aquifer have been mapped (Figure 21):

- SA_L Quaternary aquifer/ aquitard units directly underlain by the Lower Fars Formation as a basal unit (regional aquiclude).

- SA_U Quaternary sand and gravel aquifer underlain by the Upper Fars Formation as a basal unit.

- SA_S Coastal and inland sabkhas.

- SA_M Quaternary sand and gravel aquifer underlain by tectonically emplaced dark Marlstones and shales as main basal unit.

- SA_J Quaternary sand and gravel aquifer east of Jebel Hafit (Al Jaww Plain), underlain by Upper Fars and Lower Fars Formations as basal unit.

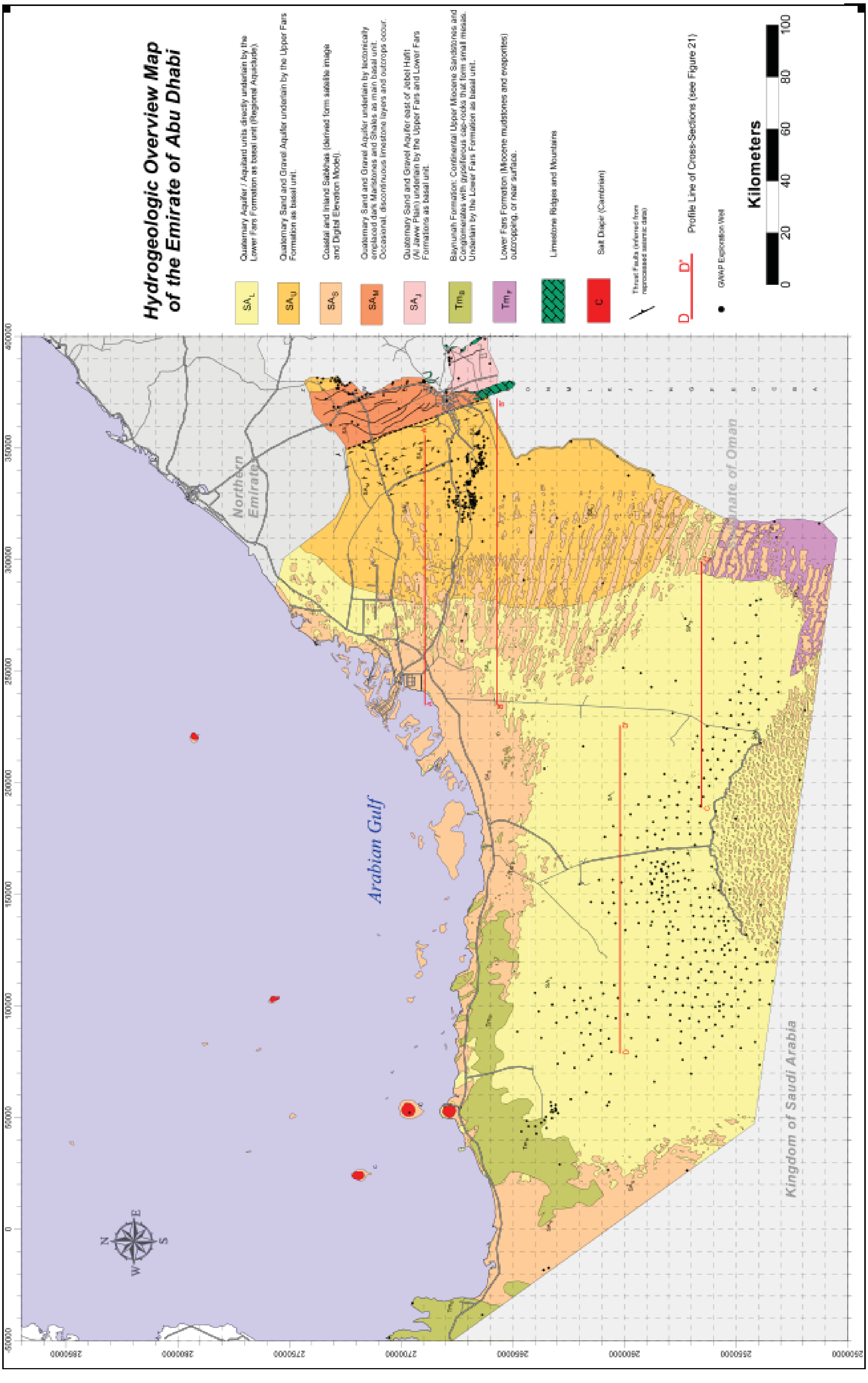


Figure 21: Hydrogeological map of Abu Dhabi Emirate.

According to GTZ (2005a), the "shallow aquifer comprises all permeable layers that are hydraulically connected and exhibit a hydraulic head that is defined by the water table for any given point…..the Upper aquifer comprises the upper part to the shallow aquifer which is generally hydraulically more active when yielding groundwater to a fully penetrating well….the lower part of the shallow aquifer can therefore often be considered an aquitard". Figure (22) shows the thickness of the upper aquifer and Figures 23a, b, c, d show the distribution of the water table (piezometric levels) found within it and also contours for the bottom of the upper aquifer and the top of the Lower Fars Formation. Figure (24) shows four hydrogeological cross sections whose positions are shown in Figures (23 b, c and d).

a) Sabkha deposits

Sabkhas are uneconomic aquifers and contain groundwater of hyper-salinity and brine quality in some places. Their distribution in the Emirate is shown in figure 10. Their hydrogeology and hydrochemistry is described in detail by Wood and Sanford (2002) and their potential for brine resources development by Czarnecki et al. (2000). The former concluded that rainfall is the dominant source of water whilst ascending terrestrial brine is the dominant source of contained solutes for the coastal sabkhas which comprise a 300 km long by 15 km (range 2-20 km) wide strip. The area is flat with topographic and groundwater gradients of 1:5000 and a depth of groundwater of between only 0.5 m – 1.0 m. The 10 m deep sabkha, which comprises uniform fine sand composed of detrital carbonates and quartz with minor amounts of feldspars, anhydrite and heavy minerals, is of Holocene age (Abu Dhabi Formation) and is superimposed over Tertiary and Pleistocene sediments. The sediments have a consistent porosity of about 38 % and field tests show a hydraulic conductivity of 1-2 m/d. The sabkha aquifer was formed 7000 and 8000 YBP and contained seawater in the interstitial pores, after which brines from the underlying Tertiary formations started to discharge into the newly formed aquifer, which serves as a regional groundwater discharge area for the deeper Paleozoic to Cenozoic aquifers. For a representative rectilinear volume of the aquifer 1 m wide, 10 m deep and 10 km long, modeling shows that less than 1 m^3/yr enters and exits by lateral groundwater flow, 45 m^3/yr by upward vertical leakage, 640 m^3/yr by recharge from rainfall and 690 m^3/yr is lost to evaporation. The major water input is therefore rainfall rather than lateral groundwater flow which, by comparison, is negligible.

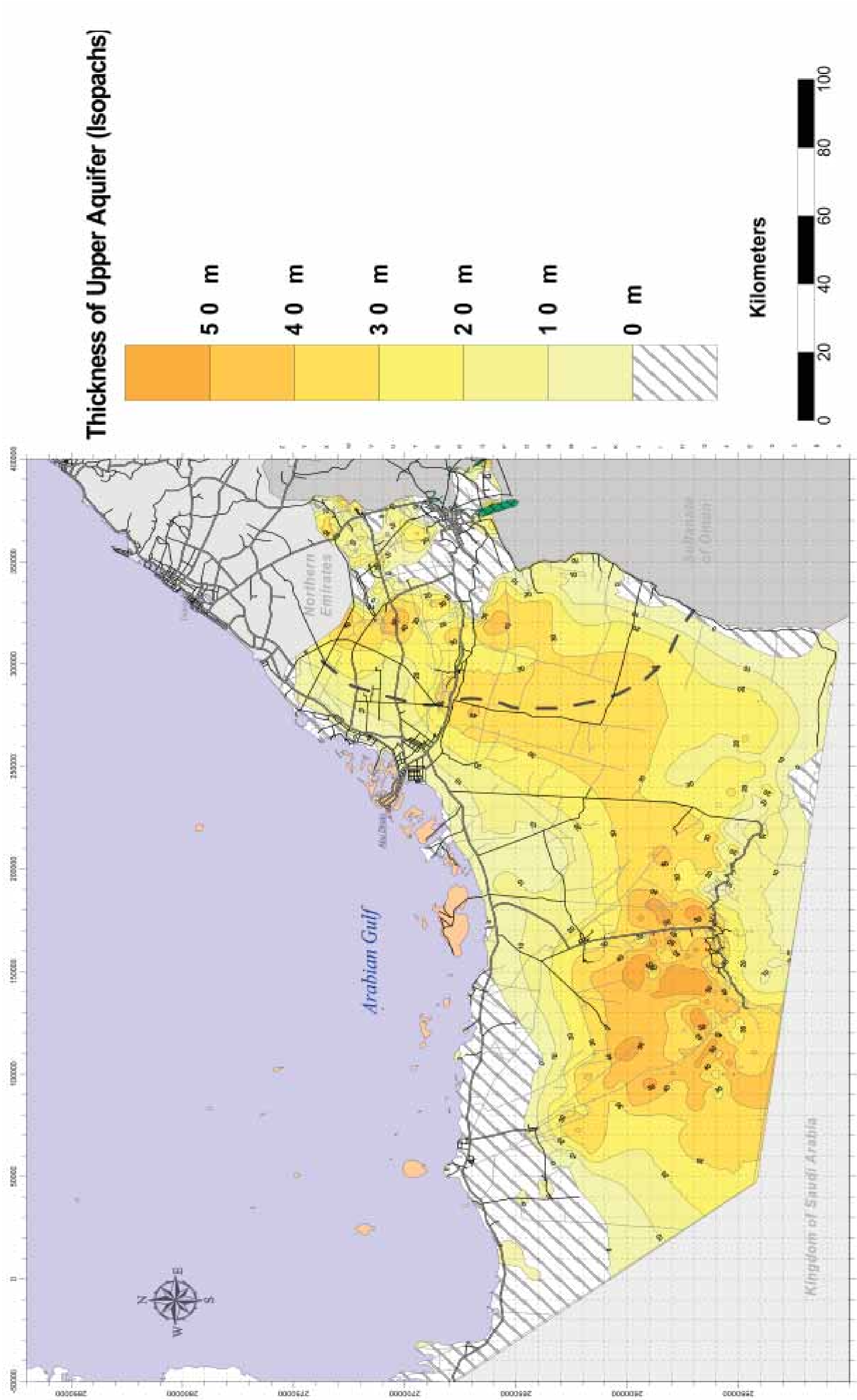


Figure 22: Thickness of the upper aquifer (GTZ, 2005a).

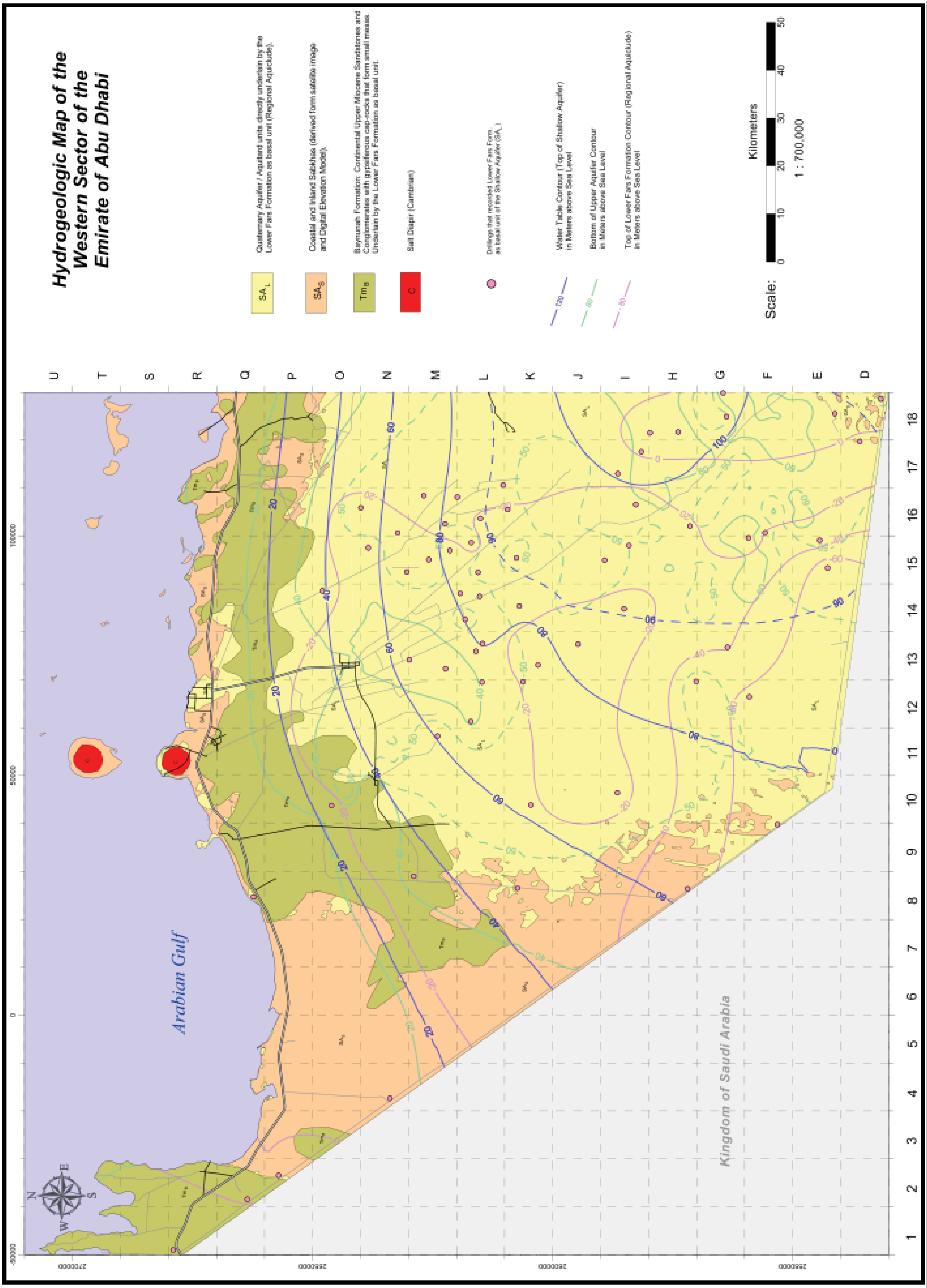


Figure 23a: Hydrogeological map of western region (GTZ, 2005a).

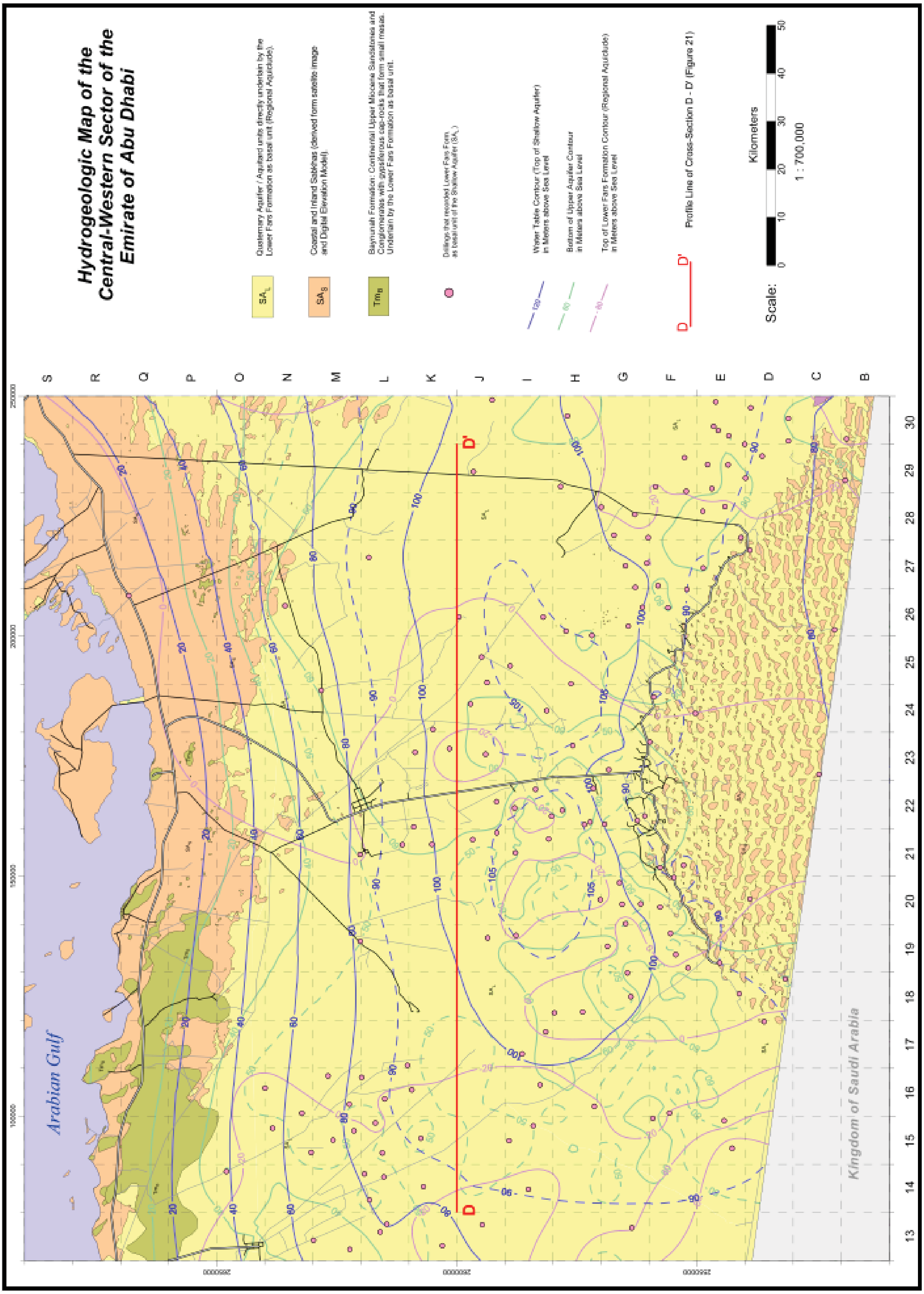


Figure 23b: Hydrogeological map of central western region (GTZ, 2005a).

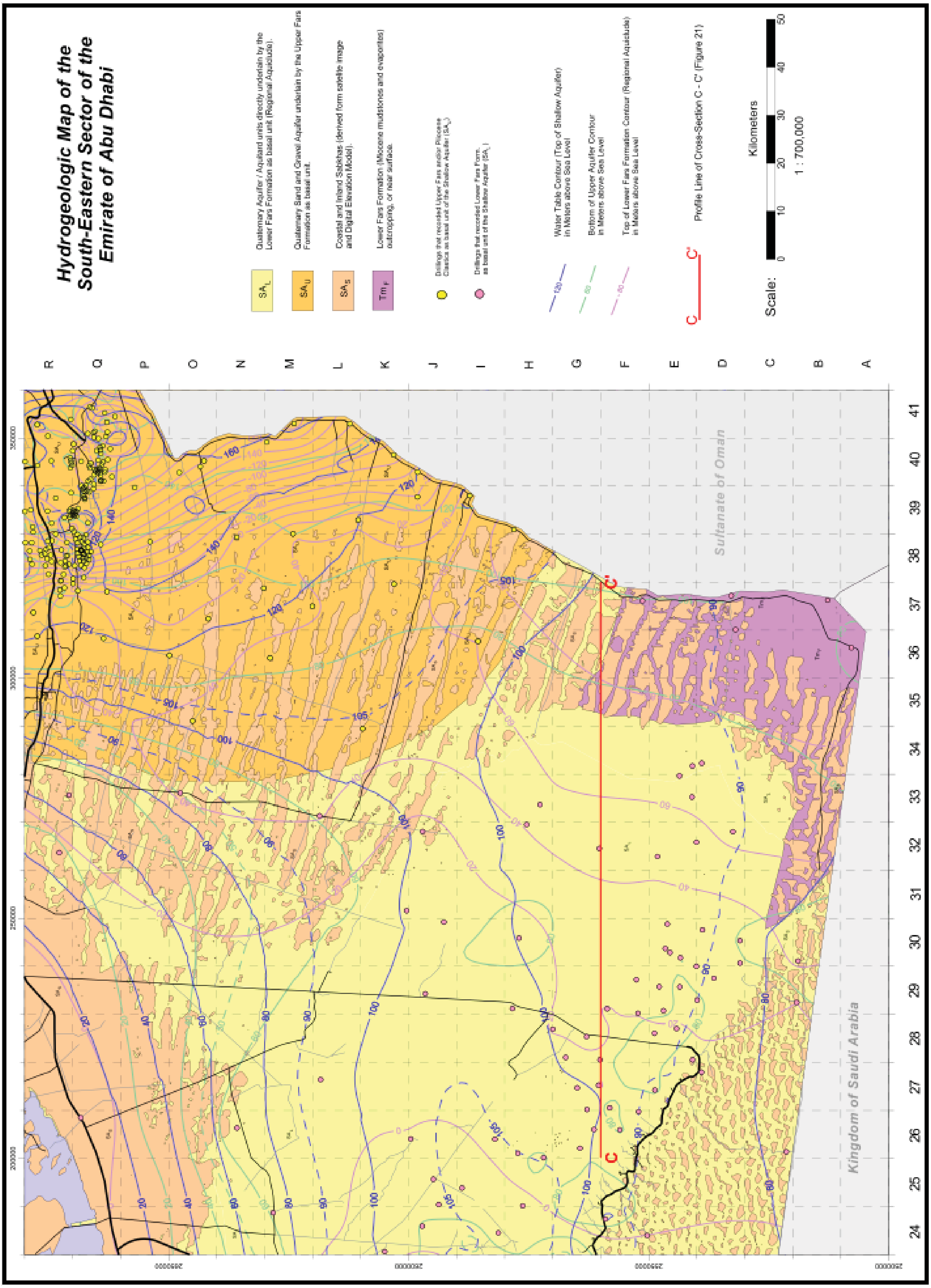


Figure 23c: Hydrogeological map of south eastern western region (GTZ, 2005a).

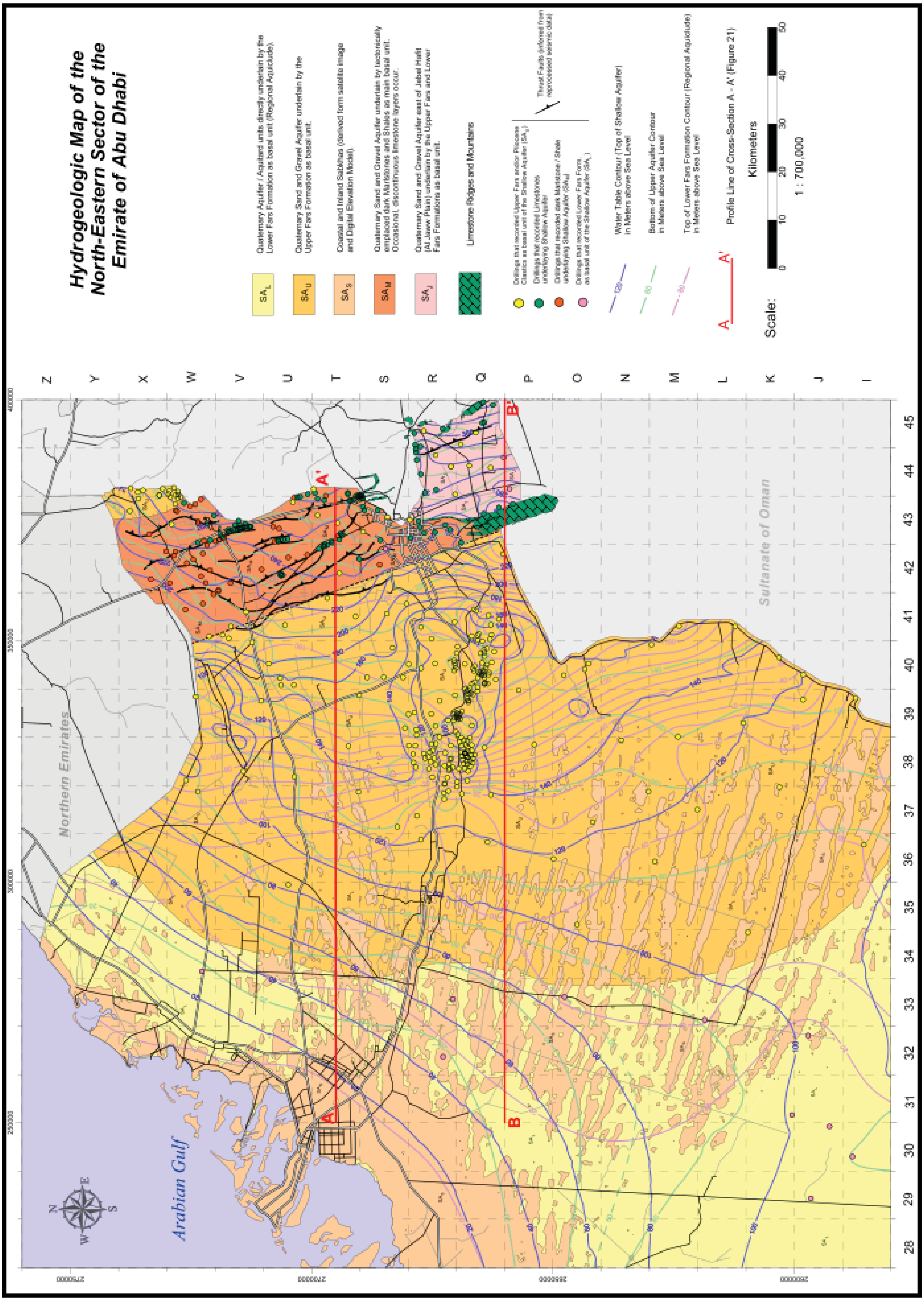


Figure 23d: Hydrogeological map of north eastern region (GTZ, 2005a).

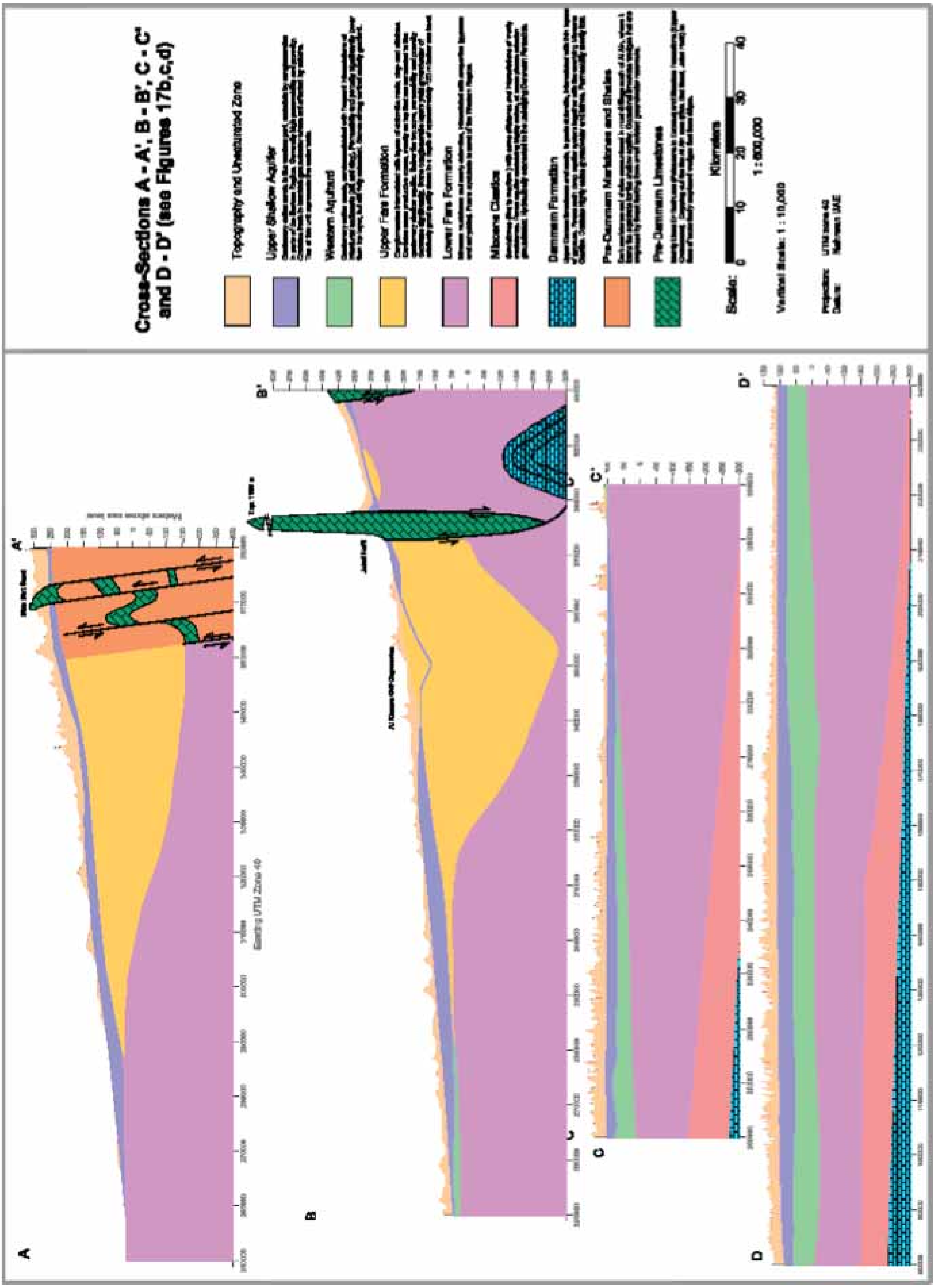


Figure 24: Hydrogeological cross – sections throughout Abu Dhabi Emirate (GTZ, 2005a).

b) Sand Dunes

Much of the Emirate is covered with Quaternary age (Holocene) aeolian sand deposits that comprise many different types of dunes, some of which occur as massive complexes. Dunes range in size from mega barchans found in the dune field directly south of the Liwa crescent where the average relative dune heights are 103 m, to small barchans south east of Baynunah which have an average relative height of less than 10 m (UAE University, 1993). The dunes are a common north – eastern extension of the well known sand sea "Ar Rub Al Khali" which lies mainly within Saudi Arabia.

Topographic elevations range from 0 m (offshore islands) to 259 m above mean sea level (mega barchan dune field south of Liwa). Inland sabkha is found within the depressions of the mega barchan dune field. The sand dune aquifer, which is dominant in the western region, comprises mostly medium to very fine grained aeolian sands, sub-rounded to well rounded, which become progressively argillaceous with increasing depth. Individual sand grains are frosted, white to reddish-orange and composed of quartz, carbonate, and dark heavy and evaporite minerals. The upper parts of the aquifer are relatively clay and silt free and thus have moderate permeability and high porosity (NDC/USGS, 1993, USGS, 1996) and this permeable and productive zone is termed the upper shallow aquifer which is underlain unconformably by the gravels and conglomerates in the eastern region and by a zone of lower permeability and productivity in the western region, termed the western aquitard (GTZ, 2005a).

This aquifer contains the fresh water basin north of Liwa Crescent (USGS/NDC, 1994) and is the beneficiary of the artificially recharged desalinated water introduced as a pilot ASR scheme (GTZ 2005b). Another fresh water mound is also found in the sand dunes of the Bu Hasa oil field (Rizk and Alsharhan, 2003b). In the Liwa area, where 2,400 km^2 are underlain by fresh groundwater (Moreland, 1998), the dune sands comprise medium to very fine grained sand with silt composed of carbonates, quartz and heavy minerals. The unconfined Liwa aquifer has an average transmissivity and specific yield of 300 m^2/d and 22 %, respectively. In the Liwa crescent area, the average thickness of fresh water is 30 m with a total storage of 16,000 Mm^3 and 101,000 Mm^3 of fresh and brackish groundwater has further been estimated (USGS/NDC, 1994). The fresh water lens has been mapped by the GWAP and is shown in Figure (25).

Whilst some, small degree of modern day groundwater recharge still occurs in the Liwa area, as proven by groundwater tritium content values, the majority of the water recharged some 6,000 to 9,000 years before present and so therefore the fresh groundwater lens is largely fossil in nature (Wood and Imes, 1995a).

c) Paleodune deposits

These are ancient consolidated sand dunes of pre-Quaternary age and occur in a belt along the northern most exposure of the SA_L mapped unit and with physiographic unit IIb of Figure (12) and occur mostly as erosional remnants within interdune sabkha areas. Their evolution has been studied in detail by Hadley et al. (1995, 1998). The deposits crop out as either minor exposures mantled by Holocene sand dunes or as relatively thick exposures that cap or flank the leeward sides of buttes formed of Miocene sedimentary rocks (Hadley, 1995). The quartz component of the dunes increases progressively from north to south so that in the Liwa area, it can comprise up to 90% of the overall paleodune deposit.

The dunes unconformably overlie the Baynunah Formation and are themselves unconformably overlain by the Holocene age sand dunes. They comprise mostly fine to medium grained , rounded to well rounded quartz sand and consist of well rounded grains with miliolid foraminifera, coral, red algae, ooids, shell fragments, evaporite minerals, heavy minerals and micritic carbonate cement. Whilst most of the dunes are found in the coastal belt described above, they are also found as far south as the Saudi Arabian border, south west of Liwa, where they crop out in interdunal sabkhas.

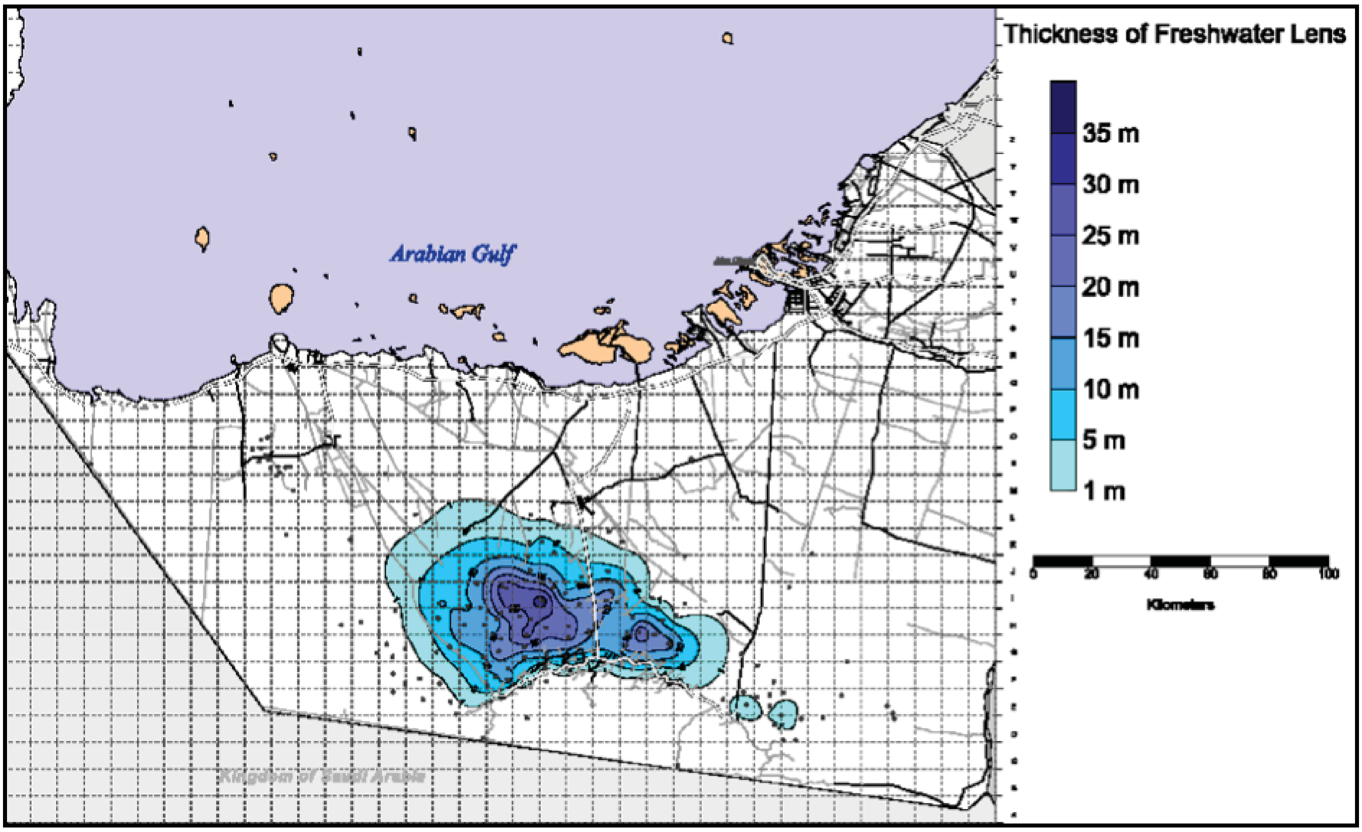


Figure 25: Map of the freshwater lens in the Liwa region (after GTZ, 2005a).

d) Baynunah Formation

The Baynunah deposit comprises poorly consolidated fluvial sand of late Miocene age and outcrops over an area of about 3000 Km² (Figure 21). Sediments are horizontally bedded and form relatively high topography up to 60 (mamsl). The formation can contain thin sandstone, conglomerate, clayey silt and gypsiferous sandstone beds. Sediment source is from the west in Saudi Arabia. Groundwater quality is highly brackish to hyper saline and there is little development potential.

Collectively, all the above unconsolidated formations form the shallow, surficial aquifer in the Emirate whose overall groundwater salinity and aquifer thickness is shown in Figures (26) and (27) respectively. The Depth to the brackish-saline interface within the upper aquifer in the western region is shown in Figure (28). The interface occurs at depths ranging from 5 m to more than 80 m below the recorded static water level in individual wells.

e) Alluvial deposits

These comprise Quaternary sands and gravels and depending on the underlying formation, have been classified into three mapped units: SA_U, SA_S and SA_J (see figure 21). In the eastern region, alluvial fans coalesce into piedmont plains which occur on the edge of the Oman Al Hajar Mountains and Jebel Hafit and can be found in physiographic zones IIf and III in Figure (12). Environmental tracers of Chloro-Fluoride Compounds (CFC) and Sulphur Hexa Fluoride (SF_6) have been used by the USGS/NDC Groundwater Research Program in the Al Hayer and Al Jaaw Plain areas of the Al Ain region (Symonds et al, 2005) in order to date the occurrence of recharge events in the alluvials. Recharge events dated from between 12-45 years and the deeper the groundwater, generally the older the age.

The sands and gravels are largely an erosional product form the Oman Ophiolite complex, whereas the smaller fans at the foot of Jebel Hafit comprise almost exclusively limestone clasts. The deposits contain clasts and boulders of gabbro, serpentinite, limestone and chert within either a fine grained cement or clay matrix. Highly productive parts of the alluvium are found in coarser grained deposits which were laid down in palaeo channels which are now buried at depth (Fitterman et al 1991, Woodward and Menges, 1991, Rizk, 1998). The alluvium also extends beneath a large area of aeolian sand along the boarder with Oman, north of Al Ain. Mapped unit SAU is the most extensive quaternary gravel sequence which is unconformably underlain by the Upper Fars Formation as the basal unit. This unit is tapped by most of the farm wells in the Al Khazna/Remah region where individual wells have been tested at rates of higher than150 m^3/hr. Here, the formation is 40-50 m thick and the groundwater salinity ranges from 1,500 – 10,000 mg/l. The alluvial deposits, along with the sand dune aquifers are the most productive of the unconsolidated units in the Emirate. Figure (29) shows the distribution of the specific capacity of wells drilled in the surficial aquifer throughout the Emirate, with some of those in the western dune sands and the eastern sands and gravels above 12 m^2/hr. The most productive wellfields are found north of the Liwa crescent and in the Al Khazna and Al Khader areas. Transmissivities range from <1 – 8,000 m^2/d with an average of 594 m^2/d.

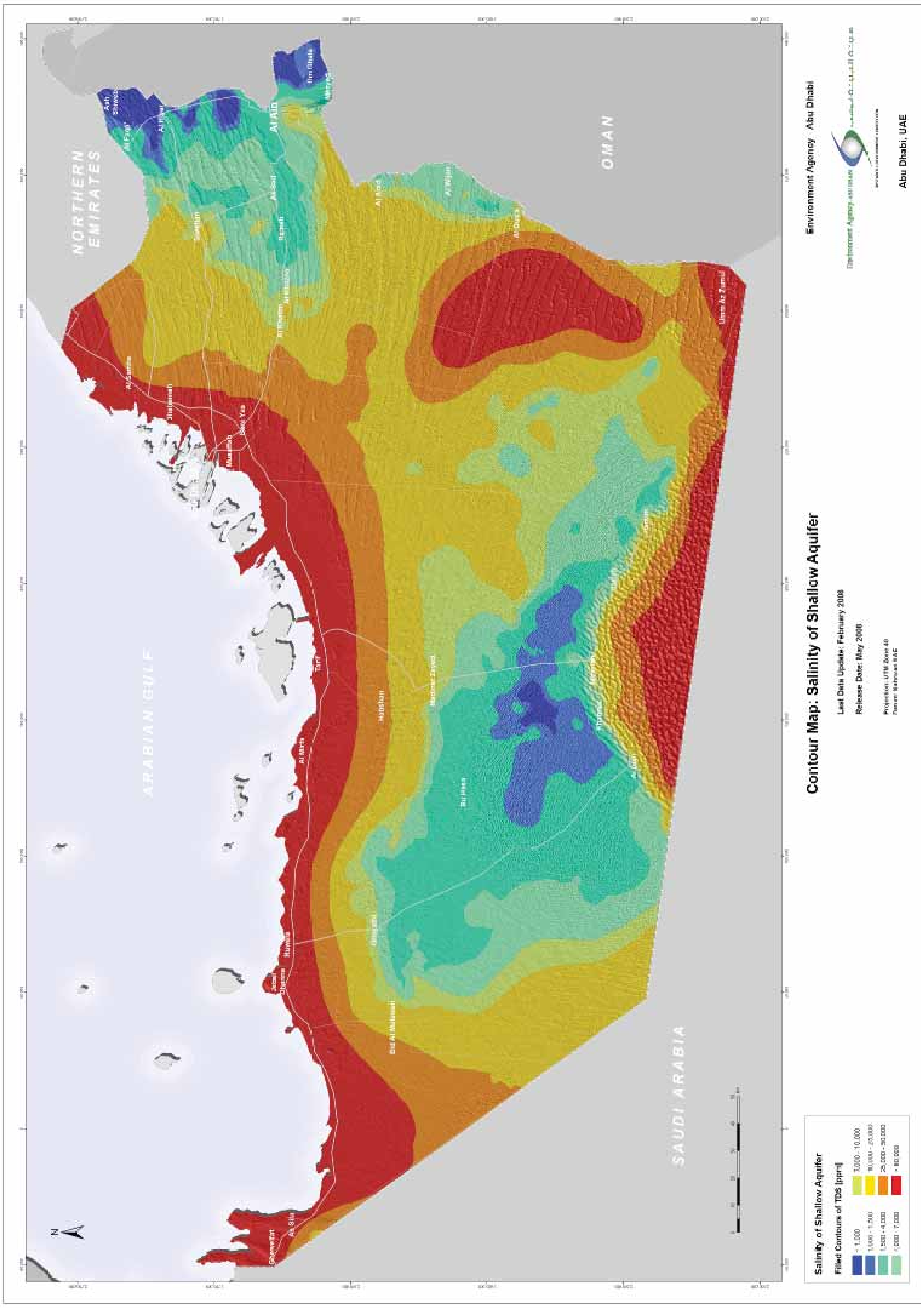


Figure 26: Groundwater salinity map for the shallow aquifer.

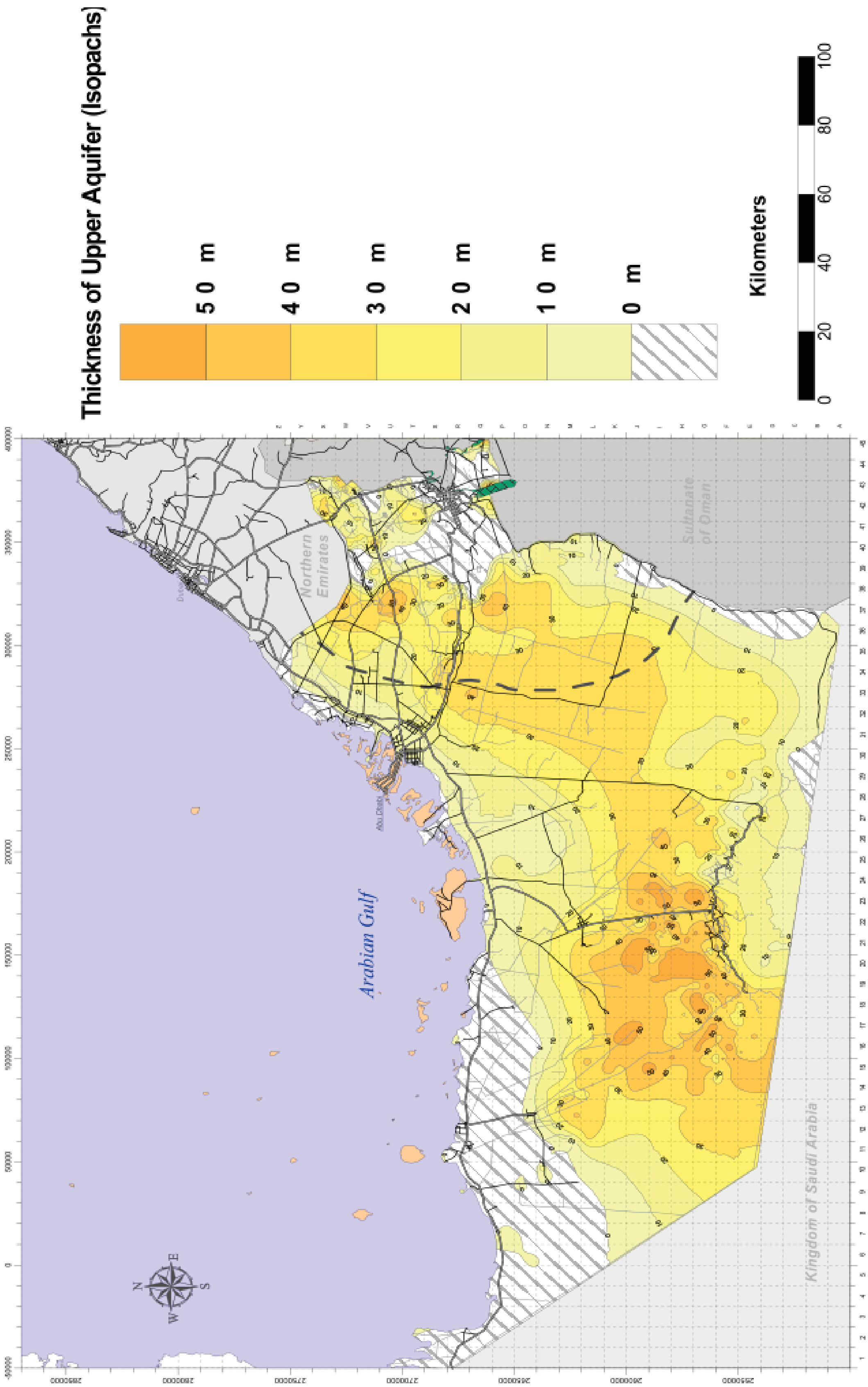


Figure 27: Thickness of the upper aquifer (GTZ, 2005a).

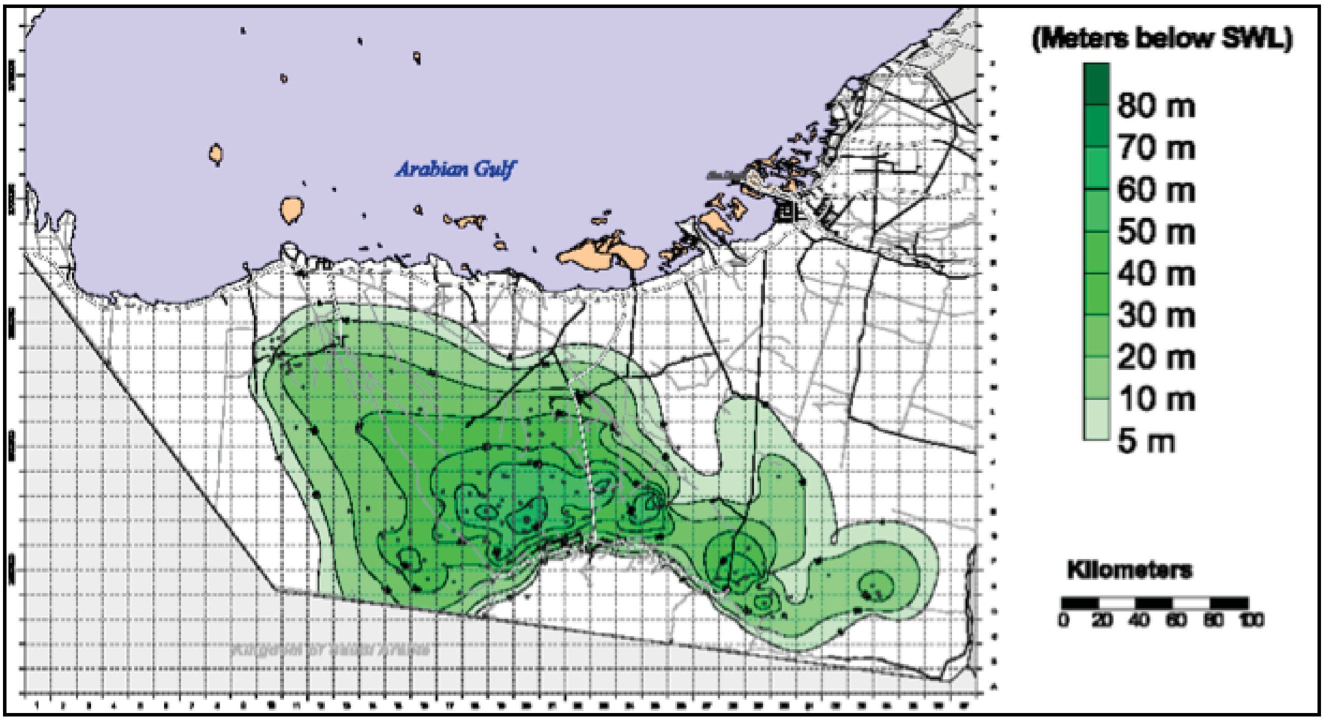


Figure 28: Depth to brackish/saline groundwater interface- upper aquifer (GTZ, 2005a).

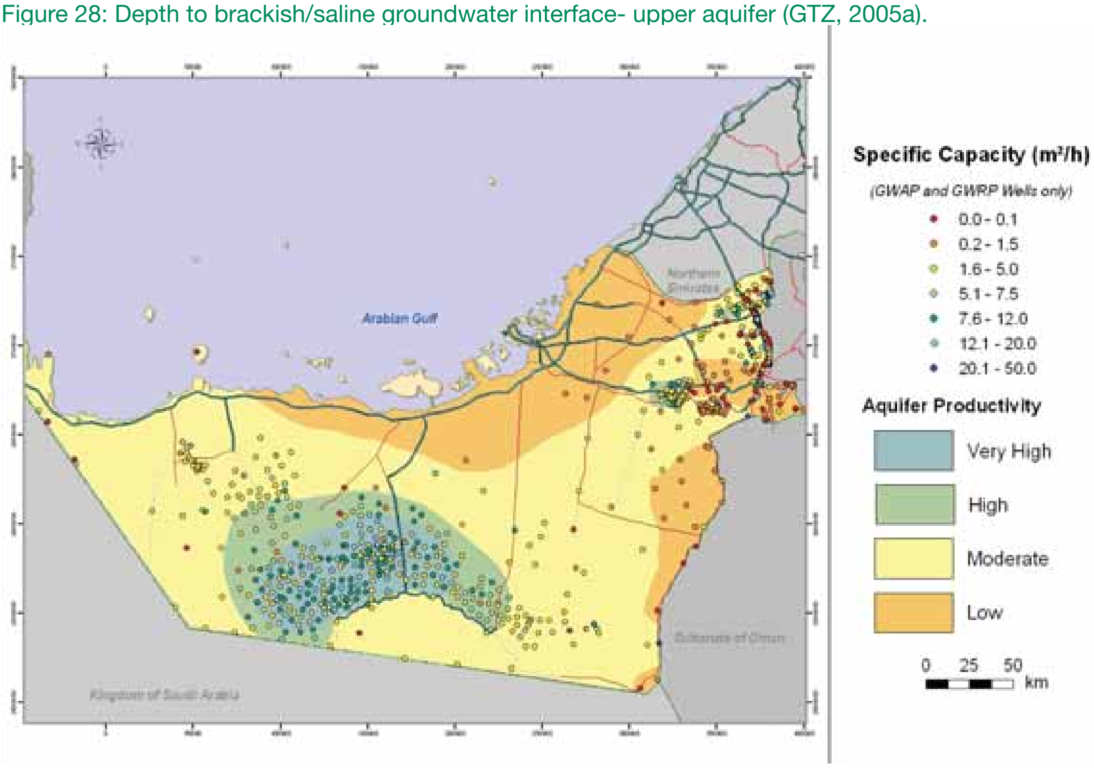


Figure 29: Specific capacity of wells drilled throughout the Emirate (GTZ, 2005a).

f) Upper Fars Formation

The Upper Fars Formation is moderately productive in some places and is present throughout the eastern Arabian shield and is a very productive aquifer in neighbouring Oman. The Fars Formation has its type locality in southern Iran where it outcrops. In neighbouring Sultanate of Oman, a $100 million groundwater fed drinking water supply scheme to 100,000 people has been developed in the locally named Al Masarrat Aquifer, to serve the Al Dhahirah region (Brook, 2001). The Upper Fars UAE equivalent underlies about 80% of the eastern Region of the Emirate, specifically occurring under mapped units SA_U and SA_J, as shown in Figure 21. The Upper Fars comprises primarily conglomerates (moderate to highly productive) with inter bedded dolomitic marls, clay and siltstones. The dolomite can occur as one meter thick, impervious beds which tend to compartmentalize the aquifers, resulting in multi aquifer layers with varying hydrochemistry. This phenomenon is seen within the units which occur in the Al Wigan/Al Quaa area south of Al Ain (Khalifa, 2004, Brook, 1994). The upper zone is in hydraulic connection with the Quaternary shallow aquifer and permeability and porosity of the aquifer decreases with increasing depth. Deeper, thin conglomeritic lenses can also be productive down to depths of around 120 m below sea level. The Formation is found at its thickest in the Al Khazna area (400 m) and also west of Bida Bint Saud (300 m). In the eastern region, the Miocene Upper Fars Formation is differentiated from the Quaternary gravels that unconformably overlie it by the occurrence of more cemented conglomeritic layers which are intercalated with dolomitic marlstones and siltstones with mostly dolomitic matrices. In the western region, the Upper Fars Formation consists mainly of marl and mudstone with interbedded thin sandy layers. These altered Tertiary deposits range in transmissivity from 1 to 270 m^2/d (average 58 m^2/d) and have average well yields of 535 m^3/d (Bright & De Silva, 1998).

g) Lower Fars Formation

This Formation occurs as thick (up to 650 m) early Miocene age mudstones and marly dolomites, intercalated with evaporites (gypsum and anhydrite) deposited in a shallow marine environment. It is present throughout the Emirate largely as an aquiclude and is unconformably overlain by Upper Fars and also the western region aquitard which comprises quaternary aeolian sands with frequent intercalations of inter-dunal sediments. In the eastern region, the Lower Fars formed a sedimentary basin or trough that was filled with sediments of the Upper Fars Formation (sections A-A’ & B-B’, Figure 24). Few wells have penetrated the Lower Fars and the top of the formation has largely been mapped by use of vertical electrical sounding geophysical techniques. Figure (30) shows a contour map of the top of the Lower Fars Formation. The deepest contact occurs in a geological trough west of Jebel Hafit. At Seh Al Gharabah, the trough bottoms out at 280m below sea level. The evaporitic section of the formation consists mostly of anhydrite and represents a lagoonal type depositional environment, with the anhydritic section being generally confined to the base of the Lower Fars Formation.

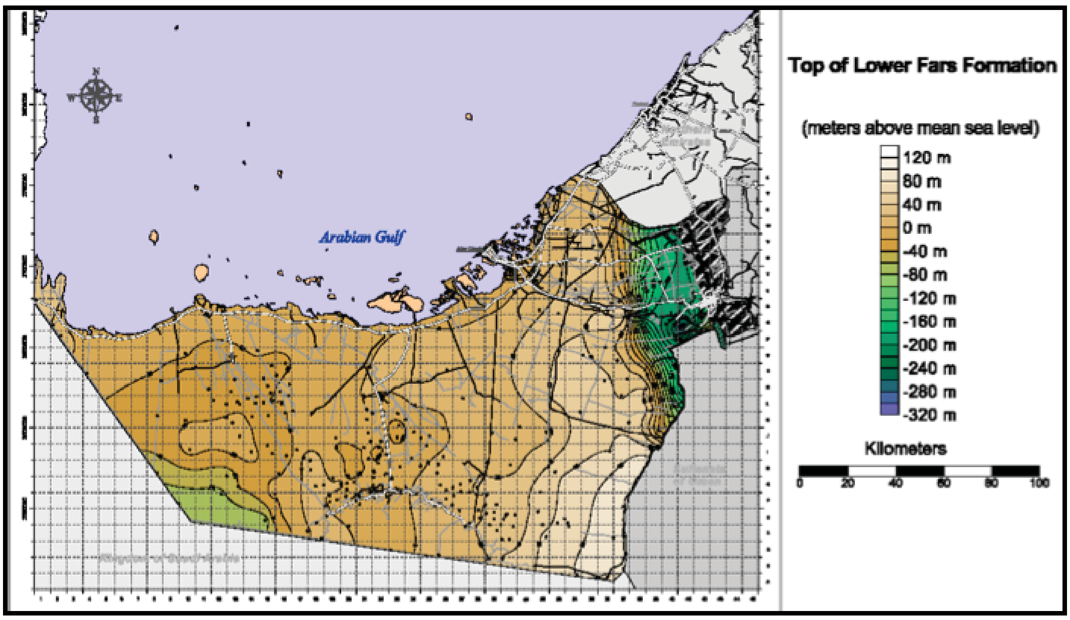


Figure 30: Contour map of the top of lower Fars Formation (GTZ, 2005a).

5.1.6 Bedrock and Structural Aquifers

Bedrock aquifers occur throughout the Emirate and are largely carbonate deposits laid down in shallow marine seas. Their potential as aquifers has not yet been fully proven; the aquifers occur generally at significant depth and have not been explored or exploited anywhere near to the same extent as the unconsolidated aquifers described above. Hydrogeological cross sections have been prepared by GWRP (USGS, 1996) based on wells which have fully penetrated the Asmari Limestone, partial penetration of the Dammam Formation and also seismic surveys. The Emirate can be divided into two structural regions as follows:

Eastern: occupies 20,340,000 km^2 and includes eastern region of the Emirate, underlain by eastern edge of the Arabian Shelf and the Oman Mountain Foredeep (Foreland Mobile Belt).

Western: occupies 47,000 km^2 and occurs in the western and central parts of the Emirate and includes the relatively stable Arabian shelf Province and Rub Al Khali basin. The main structural feature is gentle, simple folding of Tertiary strata. The karstified and fractured nature of the strata produces multi-aquifer systems (Al Mardi and Al Aidrous, 1985).

a) Asmari Formation

This Oligocene, carbonate formation occurs in both the eastern and western regions and has been relatively unexplored to date. In the western region, its equivalent occurs as an Oligo-Miocene clastic continental unit, comprising siliceous sand, sandstone and minor interbedded shale layers, whose upper contact is recognized by an overlying anhydrite bed at the base of the Lower Fars Formation (Imes et al, 1994). The continental character of the deposits is expected to grade into marine facies of shales and carbonates of the Asmari Formation along the basinal slope and further into the Eastern Region. In the eastern region, the Formation has been mapped largely from seismic profiles and has an average thickness of about 200 m. In the region of Jebel Hafit, it is significantly folded and affected by thrust faulting. The ridges are dominated by coralliferous limestones with subordinate marls rich in fossils (Kirkham, 2004).

b) Karstic Limestone Formations

These formations occur throughout the Emirate but are only exposed in the Eastern Region where they occur as fractured and solution channeled limestones of late Cretaceous to Tertiary age within a north - south trending structural zone measuring about 25 km by 80 km that represents a transition between the buried, flat lying to slightly folded strata in the Western Region and the highly deformed, uplifted rocks of the Al Hajar Oman Mountains. Rock outcrops are scarce but crystalline limestones can be found at Jebels Hafit, Muthaymimah, Malaqat, Oha, Masakin, Mohayer and at Qarn Tarab, Saba, Bida bint Saud and Mutarid in the northern structural domain. The various limestones occur along the axes of regional anticlines which have been mapped using data obtained from seismic surveys (Woodward 1990, Woodward & Jeelani, 1993) and structural analysis of borehole electrical images (Akbar, 1994, Akbar et. al, 1995). Because the outcrops are associated with steeply plunging anticlines, the aerial extent of the productive aquifers is limited to shallow horizons near the exposures (Bright & De Silva, 1998) and the aquifers were found not to be productive below depths of about 150 m below ground level. The transmissivity and therefore the individual well yield within the limestones are highly variable, ranging from 5 m^2/d to 8,700 m^2/d and 200 m^3/d to 6,000 m^3/d respectively.

c) Dammam & Rus Formations

These limestone carbonate sequences have been largely unexplored to date due to their occurrence at significant depth (>500 m below ground) although the double plunging anticline at Jebel Hafit and other anticlines has brought the formations closer to the surface and hhis allowed wells to penetrate the aquifer. Exposures of Dammam limestone can be seen at Jebels Oha and Hafit and also at smaller qarns and jebels along the eastern side of Al Jaww plain.

The Dammam, of Eocene age (54.8 to 33.7 Mya) has largely been mapped from petroleum exploration maps and dominates the crest of the Hafit structure. The marine carbonate has an average thickness of 270 m, but thins to 180 m. It attains a maximum thickness of 320 m in the Liwa region in a localized trough area. The top of the Formation marks a regional unconformity and ranges in altitude from 150 m to 1200 m below sea level. The Rus Formation is also of Eocene age and occurs directly beneath the Dammam and a 184 m section is found within the core of the Hafit anticline. In the western region, it is largely evaporitic in nature and does not constitute an aquifer. At Jebel Hafit, it comprises limestones and marls that are dominated by calcite nodules which are well cemented and therefore reduce permeability significantly.

The southern structural domain includes Jebel Hafit, the distal fold of the same area and also outcrops in the Al Jaww plain. Jebel Hafit comprises interbedded carbonate

(Dammam) and evaporite (Rus) formations and largely limestones and marls interbedded with gypsum and dolomite. The Jebel is a doubly plunging, asymmetrical anticline and the rocks are cut by numerous normal and near vertical faults and fractures providing significant secondary permeability and sometimes very high well yields. The fractures and joints provide for significant infiltration from rainfall events with relatively little run-off generated; this reduces the effectiveness of bunded structures which have been constructed at the foot of the Jebel to collect and store runoff waters for enhanced recharge purposes.

The 15-well Mubazzarah wellfield has been developed at Jebel Hafit by Al Ain Municipality with a combined daily yield of about 4,600 m^3/d. Water supplied by the wellfield has been used for recreational purposes and for "greening" of the location. Because well fractures at depths between 100-200 m below ground intersect much deeper fractures that have their origin of up to 2,000 m below ground level, groundwater in some wells attain temperatures of greater than 50 ˚C (Khalifa, 1997) and because of the mineral salts content, this groundwater has the potential for therapeutic spa treatment (REM, 2004).

d) Umm er Radhuma Formation

This Paleocene age carbonate aquifer, widespread throughout the Arabian Peninsula, forms prolific aquifers in Saudi Arabia and Oman, but does not have the same potential in UAE, especially Abu Dhabi Emirate. Very few water wells have penetrated this aquifer in the Emirate and our knowledge is restricted mostly to the southern structural domain, south of Al Ain. Attempts at deep exploration in the western region have been fraught with difficulty and campaigns have been few and to date largely unsuccessful with very high groundwater salinities and low well yields. Only one GWAP well intersected Umm er Radhuma limestone; thickness of 200 m between depths of 600-800 m below ground with a TDS content of 185,000 mg/l and a small yield of 12 m^3/hr. Further investigation into this aquifer system, however, is required.

e) Simsima Formation

This Cretaceous limestone formation occurs in the eastern structural domain region and crops out as outliers near the Al Ain–Dubai highway. Exposures of crystalline, fossiliferous limestone of the Simsima formation can be found at Jebel Mohayer as shown in Figure (31), Qarn Saba, Jebel Masakin, Qarn Tarab and Qarn Bida bint Saud. Over 40 exploration wells have been drilled into this Formation by GWAP with very variable results dependent on intersection of permeable fractures and joints which provide all the yields from the wells. Where fractures are encountered, transmissivities of greater than 3,000 m^2/d and yields in excess of 5,800 m^3/d have been reported. Figure (32) shows the aerial extent of all the karstic limestone formations described above.

Figure 31: Simsima limestone outcrop at Jebel Mohayer.

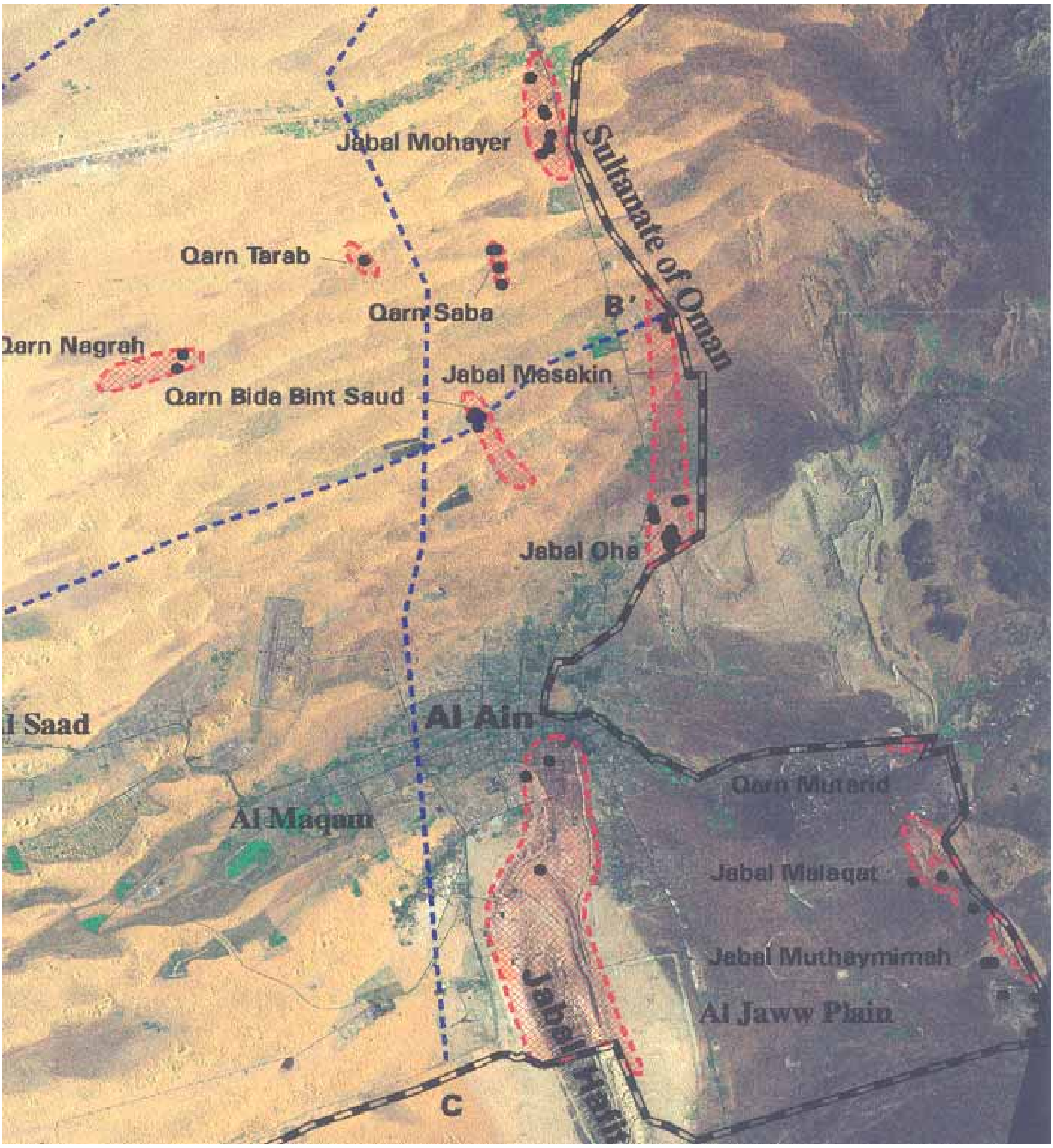


Figure 32: Location of karstic formation exposures in Eastern Region (from Bright and De Silva, 1998)

5.1.7 Groundwater Flow Systems

Groundwater flow systems in the Emirate are controlled by recharge processes, the geology of the host rocks, and long residence times of groundwater and discharge processes. The residence time in the aquifers also impacts groundwater quality. Other factors that affect groundwater quality include recharge process, anthropogenic activity such as farming and development, availability by aquifer type, extraction rates, and upward leakage from deeper formations which are generally more saline.

Table (9) shows the characteristics of the three major groundwater flow systems found in the Emirate (EAD 2006). Local flow systems are characterized by active recharge and groundwater occurs as springs and in shallow hand dug wells, Aflaj nad shallow boreholes within the surficial alluvium. These flow systems are found mostly in the Eastern region and close to the Oman border. For intermediate flow systems, groundwater occurs in relatively thin sand aquifers, low groundwater velocities with moderate residence times and inland sabkhas are main discharge sites. There is little active recharge and groundwater quality is generally brackish to saline and hypersaline at sabkha discharge sites. Regional flow systems are characterized by slow moving, with long residence times of 15,000 years. Groundwater moves slowly towards the northwest and the Gulf and also to the southwest into Saudi Arabia where discharge areas are low lying sabkhas, and discharge area have high temperatures and are highly mineralized with hyper-saline sabkha environments.

Table 9: Groundwater flow systems in the Abu Dhabi Emirate (after EAD 2006)

System Type	Main Physical and Development Characteristics	Main Hydrochemical Characteristics
Local	Occurs as springs, shallow hand dug wells, Aflaj and shallow boreholes within surficial gravel and alluvium aquifers. Short groundwater residence time in active recharge areas, rapid hydrological cycle. Limited to Eastern region and close to the Oman boarder.	Low salinity & temperature and close to ambient air temperature. Groundwater of Bicarbonate ($HCO3^-$) type, indicative of active recharge e.g. Al Jaww plain, Gashaba, Shuwaib areas.
Intermediate	Inland sabkhas are main discharge areas. Groundwater contained in relatively thin sand aquifers, low groundwater velocities with moderate residence times.	Generally brackish to saline and of Sulphate ($SO4^-$) type. Hypersaline at discharge areas i.e. Sabkha. None or little active recharge, most of Western region has this system, although Ain bu Sukhanah spring at Ayn Al Fayda also belongs to this system.
Regional	This slow moving, long residence groundwater system moves towards the North West and the Gulf and also to the South West into Saudi Arabia where discharge areas are low lying sabkhas	Discharge areas have waters of high temperature and are highly mineralized. Sabkhas are hyper-saline. Residence times of up to 15,000 years produce Chloride ($Cl^{-)}$ water types

In the Emirate groundwater movement is generally from east to west for local, intermediate and regional flow systems, although north of the Liwa crescent, a groundwater high allows flows to the south and across the border with Saudi Arabia as shown in Figure (33). Flow times from recharge zones in the east to the sabkha discharge zones along the Gulf coastline can take up to 15,000 years. This slow groundwater movement allows for considerable dissolution of salts in the groundwater and the longer the residence time, the higher the salt content, as a consequence hyper-saline groundwater in excess of 200,000 mg/l are found along the Abu Dhabi coastline.

5.1.8 Groundwater Production

Water in Abu Dhabi Emirate is produced from wellfields, aflaj, desalination plants and from treatment of wastewater. The majority of water is produced from abstracting groundwater, and from desalination processes. Environment Agency – Abu Dhabi (EAD, 2006) analysis of all water produced and shows that the vast majority (81%) is abstracted from boreholes and shallow dug wells; the remainder is produced from desalination of seawater (15%) at four main plants situated along the Arabian Gulf coastline at Al Mirfa, Abu Dhabi, Um Al Naar and Al Taweelah, and from 22 sewage treatment plants (4%). Water used for domestic purposes is abstracted from 16 wellfields, and the bulk is supplied from the four main desalination plants mentioned above, in addition to small desalination units which treat brackish water in Al-Ain. Abu Dhabi topography is not generally suitable for the construction of recharge dams which trap runoff from rainfall and allow its gradual release downstream in order to recharge groundwater aquifer. Only one recharge structure, a diversion bund with several downstream recharge basins, exists in the Emirate at Al Shwaib with reserve capacity of about 32 Mm^3.

A summary of groundwater supply sources for 2003 and 2006 along with their respective supply regions are shown in Table (10) and also illustrated graphically in Figures (34) for 2003 and (35) for 2006. Approximately 2700 Mm3/yr or 79.7% was supplied from groundwater sources in 2003 which decreased to 2231 Mm3/yr or 71.4% in 2006. Groundwater supplies from agricultural wells decreased by about 10.8% between 2003 and 2006. By far the greatest percentage decrease in groundwater supplies was for forestry wells which decreased by 40.3% from 607 to 362 Mm^3/yr, and Municipal wells which decreased by 58.4% from 29.5 to 12.3 Mm^3/yr. Groundwater withdrawals from Other wells decreased by 5.1% from 110 to 105 Mm^3/yr.

Tables (11, 12 and 13) show a breakdown of water supply source regions and the production of groundwater for each of the production sources: agricultural wells, forestry wells, municipal wells, aflaj, and other wellfields.

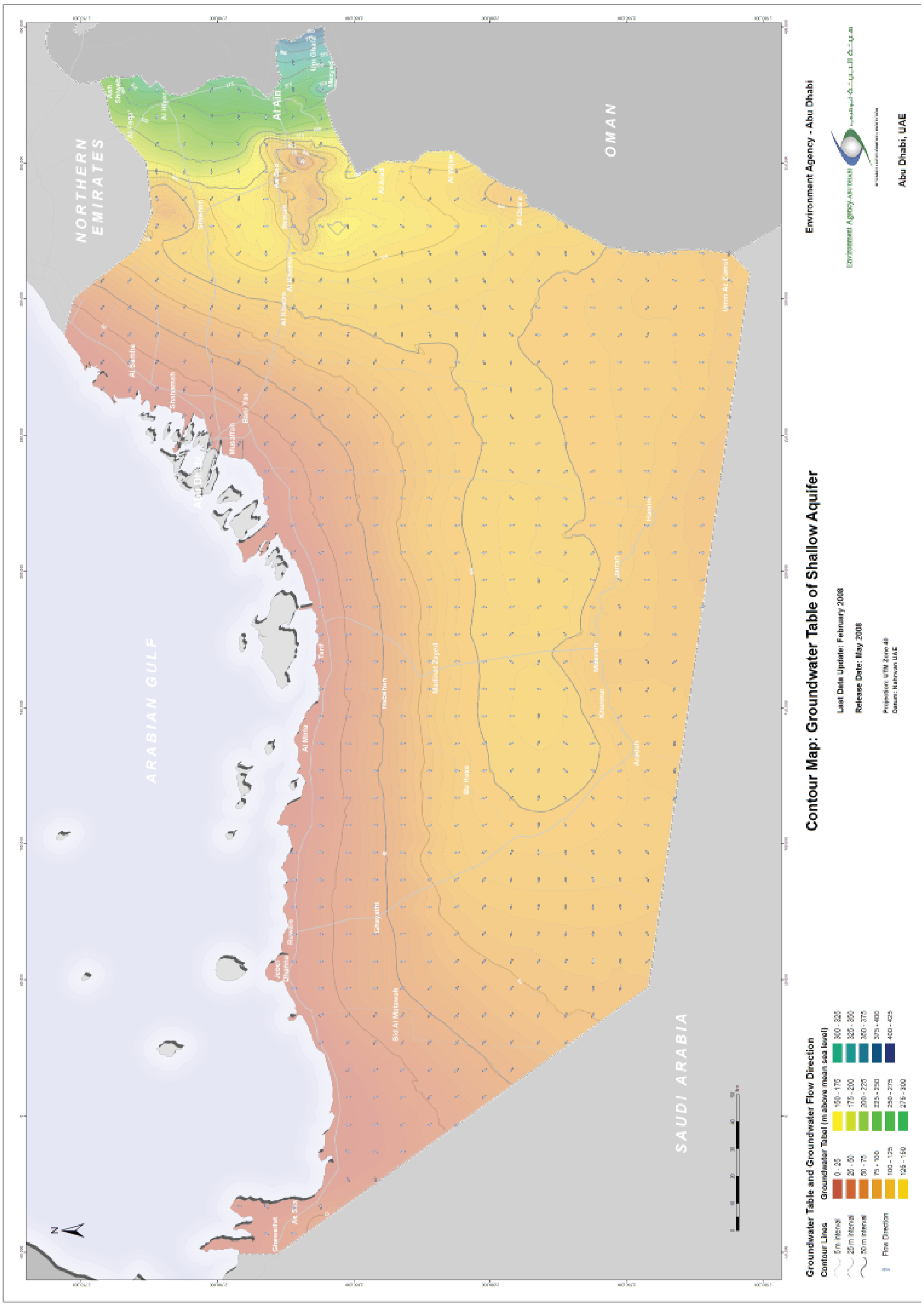


Figure 33: Groundwater flow System in Abu Dhabi Emirate.

Table 10: Summary of Groundwater Supply Sources for 2003 and 2006.

Supply Centres	Supply Regions (Mm3/yr)							
	Eastern	Central & Western	Inter Emirate Transfer	**Total 2003**	Eastern	Central & Western	Inter Emirate Transfer	**Total 2006**
Agriculture wells	1109.07	843.29		1952.36	979.81	761.62		1741.43
Forestry wells	122.85	484.45		607.30	124.98	237.4		362.38
Municipal wells	25.78	3.67		29.46	10.28	1.98		12.26
Aflaj	0.50			0.50	10.00			10.00
Other Wells	89.71	20.81		110.52	86.18	18.67		104.85
Total Groundwater Supply	**1347.91**	**1352.22**	**0.00**	**2700.14**	**1211.25**	**1019.67**	**0**	**2230.92**
Desalination	0.57	547.43	6.24	554.24	0.32	636.89	105.2	742.41
Treated Wastewater	21.28	109.57		130.85	31.52	118.37		149.89
Total Non-conventional	**21.85**	**657.00**	**6.24**	**685.09**	**31.84**	**755.26**	**105.2**	**892.3**
Total Water Supplies	**1369.76**	**2009.22**	**6.24**	**3385.23**	**1243.09**	**1774.93**	**105.20**	**3123.22**

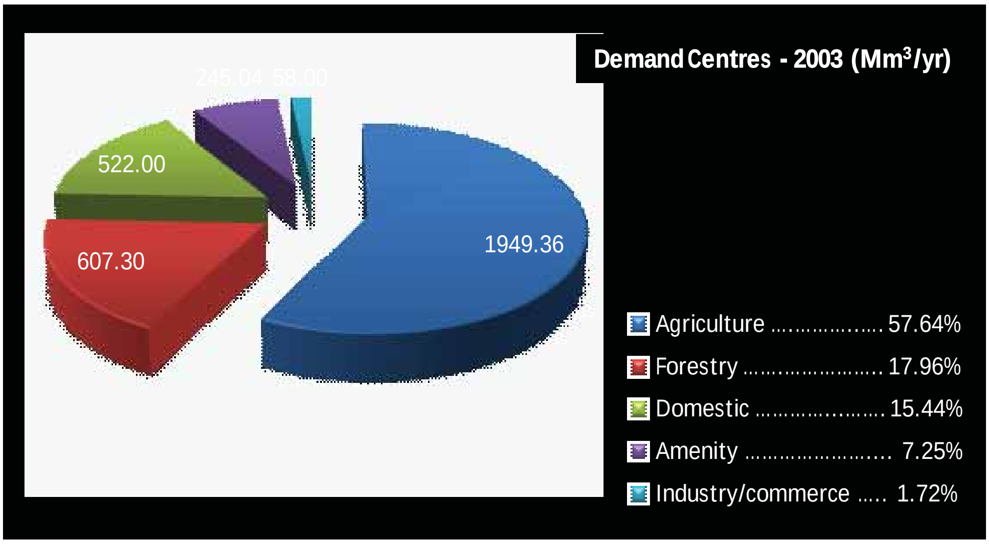


Figure 34: Demand Centres in the Emirate of Abu Dhabi for 2003

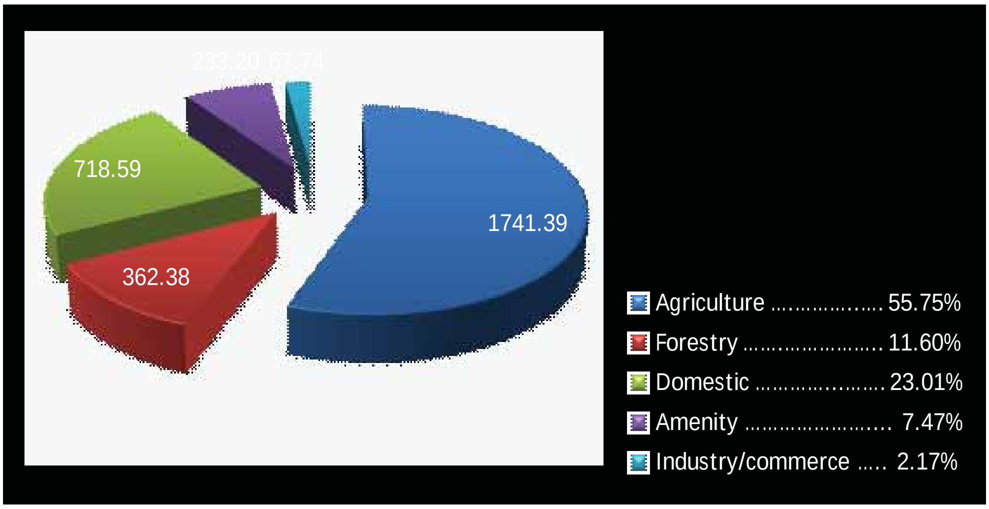


Figure 35: Demand Centres in the Emirate of Abu Dhabi for 2006

Table 11: Water Production from Agricultural and Forestry Wellfields

Agriculture Water and Aflaj Source - Region	Total Wells	Operating Wells	Production – 2003 (Mm³/yr)	Production – 2006 (Mm³/yr)
Eastern Region			1109.07	979.81
Central and Western Region			843.29	761.62
Total			**1952.36**	**1741.43**
Forestry Water Sources - Region	**Total Wells**	**Operating Wells**	**Production – 2003 (Mm³/yr)**	**Production – 2006 (Mm³/yr)**
Eastern Region			122.85	124.98
Central and Western Region			484.45	237.40
Total			**607.30**	**362.38**

Table 12: Water Production from Municipal Wellfields and Aflaj

Municipal Well Water Source Region	Total Wells	Operating Wells	Production 2003 (Mm³/yr)	Total Wells	Operating Wells	Production 2006 (Mm³/yr)
Eastern Region	660	333	25.78	211	211	10.28
Central and Western Region	30	30	3.67	20	17	1.98
Total	**660**	**363**	**29.46**	231	228	**12.26**
Aflaj Water Source	**Total Aflaj**	**Operating Aflaj**	**Production 2003 (Mm³/yr)**	**Total Aflaj**	**Operating Aflaj**	**Production 2006 (Mm³/yr)**
Eastern Region (Al Ain)	12	8	**0.5**	12	6	**10.0**

Table 13: Water Production from Other Wellfields (Amenity and Recreation)

Other Wellfields Water Source Region	Total Wells	Operating Wells	Production – 2003 (Mm³/yr)	Production – 2006 (Mm³/yr)
Eastern Region[1]			89.71	86.18
Central and Western Region[1]			20.81	18.67
Total			**110.52**	**104.85**

[1] Note: calculated from balance of treated effluent production

Although Table (11) shows the total estimated production from agricultural and forestry wells for the Eastern region and the Western region, much better information is required on the distribution of production, especially because the bulk of groundwater extraction totaling 2104 Mm^3/yr occurs for irrigated agricultural and forestry. In order to improve management of groundwater resources, metering of wells at the farm level is required so that effective conservation and management strategies can be put in place. This may be considerably easier to implement for the forestry sector since much of the forest irrigation falls within the jurisdiction of government ministries.

As well yields have declined and the groundwater quality has declined the production from municipal wellfields has decreased by over 50 percent as shown in Table (12). Much of the existing production for the Eastern region comes from 3 wellfields: the Kashona wellfield which has 29 production wells and produces 3.6 Mm^3/yr; the Al Karaa wellfield which has 58 production wells and produces 2.89 Mm^3/yr; and the Shuwaib wellfield which has 47 production wells and produces 2.12 Mm^3/yr. Together these 3 wellfields account for 83.9% of all water production from municipal wellfields in the Eastern Region.

As stated earlier, there appears to be some discrepancies in the amount of water production from Aflaj sources. This needs further investigation so that a clear picture can emerge as to how much of the groundwater is being used to support the Aflaj systems. This will in turn allow an improved assessment of groundwater levels and quality. Finally, the amount of groundwater being extracted from other wellfields is currently estimated as an excess amount from the water balance. The location of these wells and the amount of groundwater being extracted are required to improve conservation and management of the resource.

Table 14: Calculated Groundwater Production in Abu Dhabi Emirate 2006.

Municipal Wellfields			
Eastern Region[1]:	Well Field	No. Producing wells	Production Mm³/ yr
(Potable supply is blended with desalination water for Al Ain Domestic supply)	SHUWAIB NORTH	47	2.12
	SHUWAIB SOUTH	4	0.02
	AL KHADAR	3	0.07
	AL HAIYER	5	0.15
	AL KARAA	58	2.89
	BIDA BINT SAUD	39	0.95
	GHASHABA	*	0.00
	AL ZAROUB	*	0.00
	KASHONA	29	3.60
	AL HAIYER	4	0.21
	UM GHAFA	19	0.17
	AL ASHOOSH	*	0.00
	JABAL OHA	3	0.10
	AL WAGAN	*	0.00
	AL QUA	*	0.00
	AL ASLAB	*	0.00
	SEIH AL RAHEEL	*	0.00
	Total	211	10.28
Western Region Wellfields[2] (non-potable)	Busaddain, Liwa	17 out of 20 in operation	**1.98**
	Total	241	1.98
Total Water Production from Municipal Wells:			**12.26**

Table 14 continued: Calculated Groundwater Production in Abu Dhabi Emirate 2006.

Aflaj Systems (only present in Eastern Region) [3]		
	Aflaj Name	**Number of Aflaj**
Partially supported by wells	Al Daoudi Falaj Al Aini Falaj (Al Ain City)	2
Supported by variety of sources -groundwater wells, piped desalinated water and treated effluent	Al Mutared Falaj Al Mouaiji Falaj Al Jimi Falaj Al Qattara Falaj Al Hili Falaj Maziad Falaj	6
Not operating	Al Jahili Falaj Saa Falaj Al Mazimi Falaj Al Raki Falaj	4
	Total	**12**
Forestry Wellfields		
Eastern Region:	124.98	
Western Region:	237.40	
Agriculture (Wells & aflaj)		
Eastern Region:	979.81	
Western Region:	761.62	

Total Groundwater Abstraction is about 2230 Millions m^3/year.

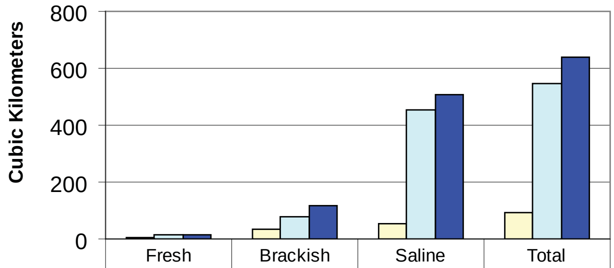
5.1.9 Groundwater Quality

Fresh groundwater reserves are found in the surficial aquifer in the recharge area near Al Ain and beneath the sand dunes north of the Liwa Crescent. A few isolated bodies of fresh ground water are known to exist in some locations where local rainfall has accumulated in thin lenses of fresh water floating on top of more saline water. Although most these thin, fresh groundwater lenses are not considered to be a significant resource, however, in a few areas of the Emirate, these isolated layers of fresh water are thick enough to yield fresh water. For example, fresh water from drilled wells has been reported to occur near well GWP-150, south of Ghayathi (USGS 2007).

Moderately-brackish groundwater is found on the fringes of the fresh groundwater areas and around the Liwa mound. Two zones of moderately-brackish water extend from the fresh groundwater mound underlying the Liwa Crescent area. One zone extends northwest toward Ghayathi and the other extends easterly toward the southeastern corner of the Emirate. In the Eastern Region, a zone of moderately-brackish water extends west toward Al Khaznah. Figure (36) shows the volume groundwater reserve in Abu Dhabi Emirate classified according to the groundwater quality whilist Figure (37) shows the groundwater quality reserve classified according to the aquifer system.

On the east side of Jabal Hafit, salinity levels increase over a relatively short distance near the base of the mountain. Fresh groundwater probably mixes with upwelling brackish groundwater or saline deep basin brines. On the west side of Jabal Hafit increases in salinity are in part due to the upward movement of deep-basin brines through underlying fractured bedrock (Imes, et al 1993).

Salinity levels increase sharply southward from the Liwa Crescent area. High rates of evaporation in the interdunal sabkhas south of the Liwa Crescent have increased the concentrations of dissolved solids to more than 100,000 mg/l. Moreland et al (2007) indicated that nitrates, fluoride, boron and chromium concentrations in fresh groundwater in the surficial aquifer exceed WHO guidelines. Average nitrate and boron concentration in groundwater increase with increasing salinity.



	Fresh	Brackish	Saline	Total
Eastern Region	4	35.9	53.3	93.2
Western Region	12.5	79.9	455.3	547.7
Total	16.5	115.8	508.6	640.9

Groundwater Type

Figure 36: Groundwater reserve in Abu Dhabi Emirate.

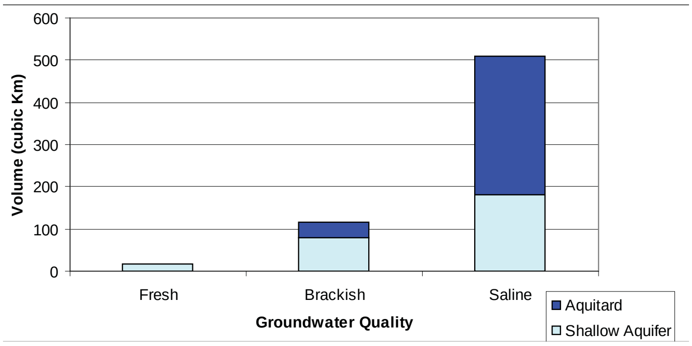


Figure 37: Groundwater Quality

Nitrates

In Abu Dhabi, the farming areas in the east are upon sandy permeable soils which overlie an interbedded section of gravels, sands and clay-silts which support a shallow and normally unconfined aquifer with static water levels between 10-20m; and a pattern of over application of fertilizer (in particular urea) and, under continuous crop irrigation, it must be assumed that a nitrate flux moves down the soil profile and into the aquifer. To investigate whether this process is contributing nitrate to the aquifer, the USGS-NDC project has monitored the profile for nitrate, in a series of piezometers; monitoring has mainly been concentrated at the margins of wellfields used for potable water supply.

Most of wells sampled in the surficial aquifer have nitrate concentrations below the 50 mg/l guideline for drinking water as shown in Figure (38). However, excessive nitrate concentrations occur naturally in many wells in the Liwa Crescent (Dawoud, 2008). High concentrations of nitrates were reported in the Liwa fresh ground water area by Wood et al (2003). Since there is a lack of vegetation in the arid climate of Abu Dhabi, there is little or no nitrogen up-take from the soil so nitrate concentrations continue to increase over time. The highest concentrations of nitrate occur in the saline water zones where evaporative concentration in sabkhas is a controlling factor.

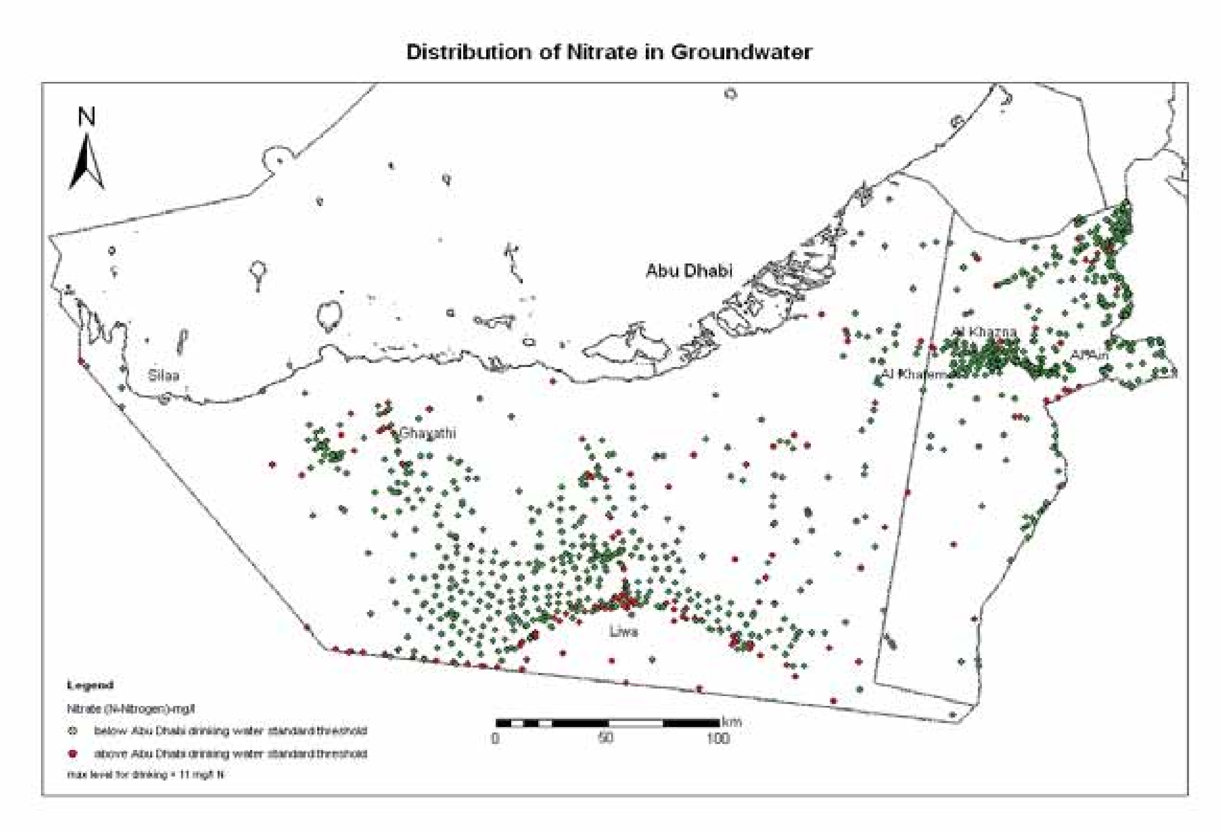


Figure 38: Distribution of Nitrate in Groundwater in Abu Dhabi Emirate.

Many of the wells in the Liwa Crescent area that contain high concentrations of nitrate are located near farming areas as a result of nitrogen fertilizer applications and represent the main reason for the elevated concentrations of nitrate in groundwater in the Liwa aquifer. Wells at Al Karaa produce fresh groundwater of average salinity around 850 S/cm. Nitrate concentrations in most wells were less than 10 mg/l as NO_3 and these were considered to represent 'ambient' nitrate levels (12 samples; average nitrate 9.7 mg/l as NO_3) but some nitrate concentrations were up to 33 mg/l. In the Central Region at the Al Wathba Wetland, monitoring work by EAD has indicated groundwater nitrate values exceeding 200 mg/l as NO_3 (EAD, 2006). Local observation and piezometric evidence strongly suggests that nitrate is entering the groundwater system from fertilizer application at a nearby camel fodder farm. The shallow aquifers in Eastern Abu Dhabi need assessment for their vulnerability to nitrate pollution from agriculture, which is reported to use excessive amounts of chemical fertilisers (mainly urea). Monitoring of the soil-aquifer profile is underway at the margins of wellfields but results and conclusions have yet to be published. High nitrate in groundwater is likely to be an indicator of excessive and wasteful fertiliser use and measures to regulate fertiliser application and irrigation/tillage timing will clearly lead to farming economies.

Fluoride

The mineral fluorapatite is found in the heavy mineral component of windblown sand and is the probable source of fluoride (Wood et al (2003). In the western region concentration of fluoride in fresh groundwater are more than 10 times greater than in the eastern region and in many wells fluoride concentration exceed 1.5 mg/l (WHO drinking water guidelines). Higher concentrations are most likely due to the longer residence time of ground water in contact with fluoride minerals along the flow path. In the eastern recharge areas the residence time of the ground water is relatively short and concentrations of fluoride salts do not build up, consequently the fluoride concentration in ground water in the Eastern Region is generally small.

Boron

Boron concentrations exceed 500 µg/l, which is the WHO guideline for drinking water in most areas of the Emirate. Concentrations of boron in groundwater in the surficial aquifer increase with increasing salinity levels and are controlled, in part, by evaporation. The source of boron in the surficial aquifer is derived from trace minerals from the ophiolitic rocks of the Oman Mountains, and possibly from mixing of saline water that has leaked upward from underlying strata of marine origin.

Chromium

Groundwater in most of the Emirate contains chromium in excess of WHO drinking water guidelines of 50 µg/l. In the Liwa Crescent area chromium concentrations of ground water exceed WHO guidelines but are generally lower in the eastern recharge areas. Wells in the northeastern recharge area near Al Ain and Mohayer have water with chromium concentrations below the WHO drinking-water requirements. The highest chromium concentrations occur where the surficial aquifer contains saline water. In the western area high concentrations of chromium in fresh groundwater indicate that geochemical processes rather than evaporation affect chromium concentrations. Chromium concentrations in ground water build up due to longer residence time of groundwater in the western areas.

5.2 Non-Conventional Resources Desalination

5.2.1 Desalination

a) Historical background

Desalination is a process that removes dissolved minerals (including but not limited to salt) from seawater, brackish water, or treated wastewater. A number of technologies have been developed for desalination, including reverse osmosis (RO), distillation, electrodialysis, and vacuum freezing. Two of these technologies— RO and distillation—are being considered by municipalities, water districts, and private companies for development of seawater desalination in California. These methods are described below.

Desalinated seawater currently represents the primary source of potable water available in Abu Dhabi and UAE. Production is, almost exclusively, from combined power generation/thermal desalination plants operating on seawater as feed. Seawater salinity is expected to limit desalinated water production in thermal plants on the Arabian Gulf coast, and locations on the Gulf of Oman, involving inter-emirate water trading, are in operation and under review. The key feature in need of definition, as far as future desalinated water production is concerned, is future energy transfer prices, which currently are maintained well below global energy prices, but which might tend to equilibrate in future decades. Desalinated water is not an unlimited resource and water produced in this way should be reserved for essential and high added value uses.

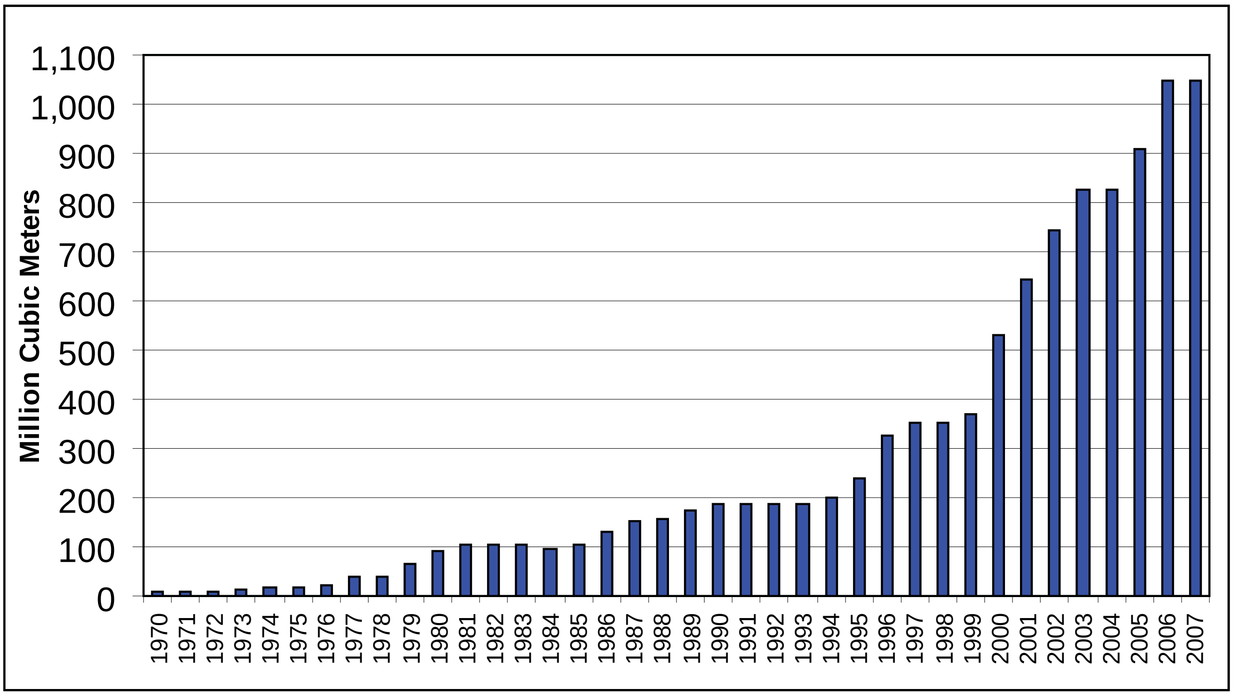


Figure 39: Desalination Capacity in Abu Dhabi (1971-2007).

b) Production

The current desalination capacity for the Emirates of Abu Dhabi is by far exceeds the domestic needs. Since some of the water is used for non-domestic uses such as irrigation and forestry. The current capacity (630 MIGD) can be better utilized if the portion used for other purposes is used for potable water uses as shown in Figure (40). The current capacity of the Emirate desalination plants is elaborated in Table (15). If out of the 630 MIGD, 50 MIGD is utilized away from irrigation or farming activities that would add more potable water to more than 200,000 people. In addition of the current production capacity, future desalination development are under various levels of plans as explained in Table (16). A total of 520 MIGD of proposed capacity are to be added to the current capacity in next few years.

c) Transmission and distribution

By introducing Shuweihat plant into service, the water supply to most of the regions in the emirate has improved. The Western region was interconnected with the Central region by transmission pipelines form this plant. Water supply to Al Ain has increased by 20 MIGD and reached 170 MIGD in 2006. This represents a 14% increase over the year before. This was mainly due to the new 185 km transmission line from Fujairah. However, 60% of the city of Al Ain is still under restricted supply. This constrains will be addressed in the year 2009 and a plan should be in place to improve the transmission system. Most of the customers in the Emirate are connected to the distribution network with 75% of them receiving a continuous supply of water.

d) Energy supply

There is a large demand for energy to run desalination plants. Thermal processes are thermal energy intensive processes while RO plants are primarily dependent on electrical energy. The energy cost in the three main processes, are $0.23/m^3 for RO, $0.33/m3 for MED and $0.46/m^3 for MSF. This suggests the high energy requirements for these processes. The energy requirement is going to grow as more desalination plants are going to be built in the new future to supply more desalinated water for the city development.

Currently, most of the energy supply comes in the form of natural gas provided for the Emirates gas supply except for Fujairah I plant where the gas is supplied form Oman. Due to the gas supply, most of the current desalination plants can run on other fuel such as diesel oil on short periods. Additional costs are associated with burning these fuels beside the environmental issues related to them. The Emirate is expected to add additional gas supply through the Dolphin project, which has the capacity to supply 2 billion cubic meter of gas on the completion of the project. While Dubai will buy a major share of this gas, Abu Dhabi Emirate should utilize the rest to supply its plants in Fujairah. Additional gas supply is expected in few years when the sour gas project is completed in the Emirate. Abu Dhabi is investing heavily in developing its gas storage and those associated with oil production. Most of this gas is sour (contains high percentage of CO_2 and H_2S). The removal of these gases is important for the gas to be used as a fuel and this extra processing should add additional cost to the gas price.

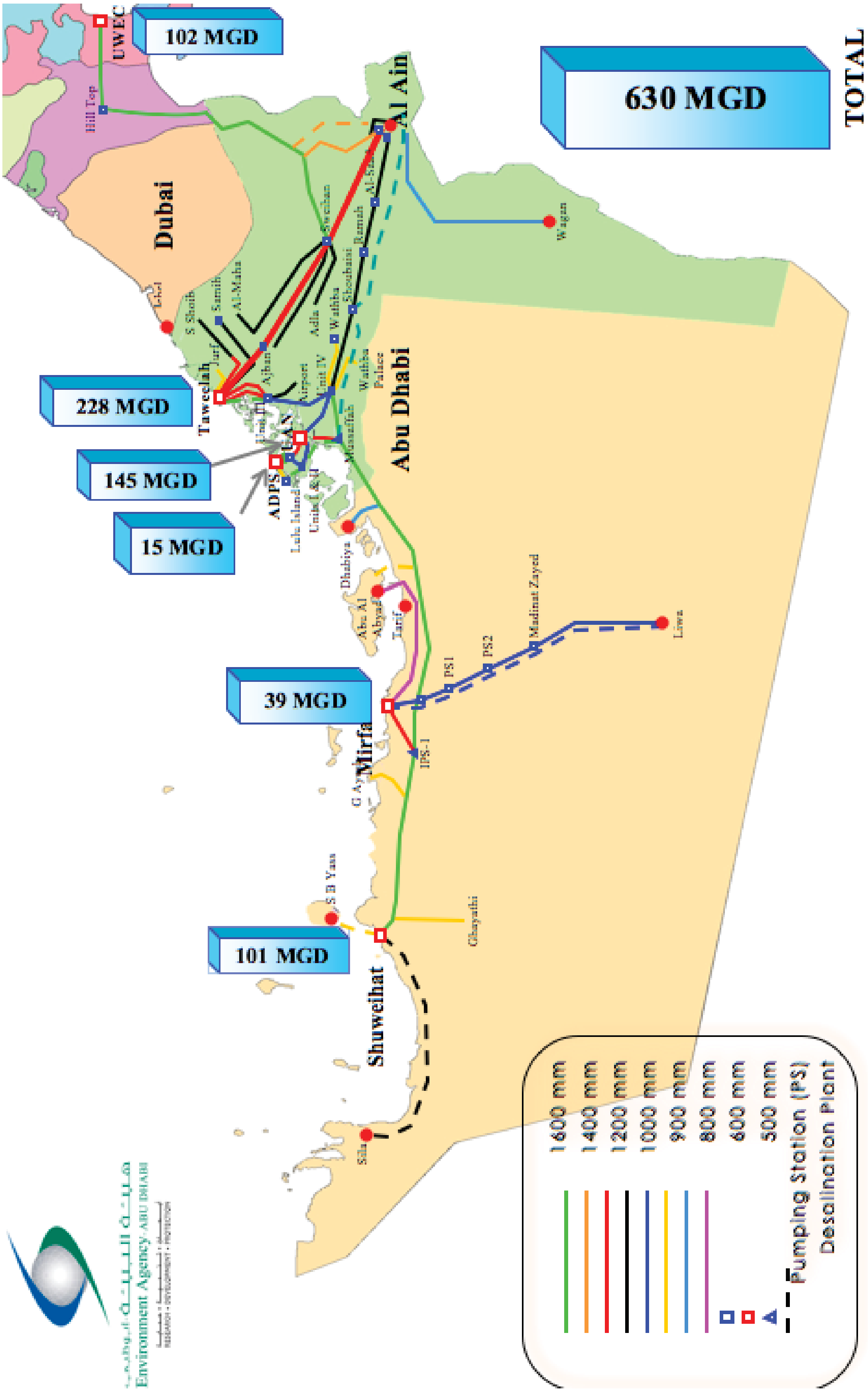


Figure 40: Desalination plants and the daily production in Abu Dhabi.

Table 15: Total Annually Desalinated Water Production in Abu Dhabi Emirate (2006).

Desalination Production				
Eastern Region[1]:	**Desalination Plant**	**Number of Plants**		**Production, Mm3/yr**
Note: Al Wagan and Al Qua'a plants closed on 1/3/03	In Al Wagan	11units (de-commissioned)		0
	In Al Qua'a	12 units (de-commissioned)		0
	In Um Al Zamool	3		0.32
	Total	**3**		**0.32**
Central and Western Region[4]:	**Desalination Plant**	**Company**	**Process Type**	**Production, Mm3/yr**
	Abu Dhabi steam turbines	Bainounah Power Company	MSF	16.32
	Umm Al Nar Power Plant	Arabian Power Company	MSF, MED	200.65
	Taweelah B	Al Taweelah Asia Power Company	MSF	119.91
	Shuweihat Power Plant	Shuweihat CMS International Power Company	MSF	102.22
	Mirfa Power Plant	Al Mirfa Power Company	ADWEA GDs	19.40
	Taweelah A1	Gulf Total Tractebel Power Company	MSF, MED	99.28
	Taweelah A2	Emirates CMS Power Company	MSF	79.10
Inter-Emirate Water Transfer :	Qidfa Fujairah	Union Water and Electricity Company	Only production sold to Abu Dhabi Emirate shown	105.20
Exports to Al Ain				(100.93)
Total Annual Desalinated Water Production (million m^3)				**742.41**

Table 16: Future Desalination Plants.

No.	Plant	Capacity (MIG)	Completion Year
1	Shwiehat – phase 2	100	2010
2	Qedfaa – phase 2	100	2009

Both sources, the Dolphin gas transported for the Qatari reservoirs to UAE and the treated sour as for Abu Dhabi reservoirs will be more costly than the current gas supply to the Emirate and that will add extra cost to the water produced from the desalination that will use these gases. Alternatively, fuel oil can be used, which is abundant, but both additional cost and environmental concerns are two major issues that need to be addressed when considering this option. Currently, fuel oil is used when there is a shortage of gas supply.

Figure 40a: Umm Al Nnar Desalination Plant in Abu Dhbai.

5.2.2 Treated wastewater

Wastewater reuse has drawn increasing attention worldwide as an integral part of water resources management. Such a move is driven by two major forces: scarcity of freshwater resources and heightened environmental concerns. Meanwhile, economical considerations are also becoming increasingly important amid the introduction of market-based mechanisms in environmental and water resources management. Reclaimed wastewater from municipalities and industries has been used as an additional source of water supply in many parts of the world, especially in areas where water resources are scarce and population and economic growth is rapid. The situation in Abu Dhabi is a typical case in point. Reclaimed wastewater can be used for many purposes, including agricultural irrigation, groundwater recharge, car washing, toilet flushing, urban lawn watering and recreational amenities, road cleaning, etc. Of all the users of reclaimed wastewater, public gardens irrigation has been by far the major user in many areas in Abu Dhabi Emirate where wastewater is reused as shown in Figure (41). This is mainly because of the large water use in irrigation, relatively low quality requirement, and relatively low cost of infrastructure for the irrigation water supply.

Reclaiming and reusing the wastewater is not a new concept. The practice can be traced back to several centuries ago. In the scientific literature, there are a large number of studies on wastewater treatment from technological and engineering aspects. Concerns on health impacts of using reclaimed wastewater, especially for irrigation and groundwater recharge have also drawn an increasing attention in the last decade. However, studies of the economic viability and institutions of wastewater reuse have been few. The followings are the advantages and disadvantages of reusing the treated wastewater:

a) Advantages

- Reduces the demands on potable sources of freshwater.
- It may reduce the need for large wastewater treatment systems, if significant portions of the waste stream are reused or recycled.
- The technology may diminish the volume of wastewater discharged, resulting in a beneficial impact on the aquatic environment.
- Capital costs are low to medium for most systems and are recoverable in a very short time; this excludes systems designed for direct reuse of sewage water.
- Operation and maintenance are relatively simple except in direct reuse systems where more extensive technology and quality control are required.
- Provision of nutrient-rich wastewaters can increase agricultural production in water-poor areas.
- In most cases, the quality of the wastewater, as an irrigation water supply, is superior to that of well water.

Figure 41: Use of Treated Wastewater in Public Gardens.

b) Disadvantages

- If implemented on a large scale, revenues to water supply and wastewater utilities may fall as the demand for potable water for non-potable uses and the discharge of wastewaters is reduced.
- Reuse of wastewater may be seasonal in nature, resulting in the overloading of treatment and disposal facilities during the rainy season; if the wet season is of long duration and/or high intensity, the seasonal discharge of raw wastewaters may occur.
- Health problems, such as water-borne diseases and skin irritations, may occur in people coming into direct contact with reused wastewater.
- Gases, such as sulfuric acid, produced during the treatment process can result in chronic health problems.
- In some cases, reuse of wastewater is not economically feasible because of the requirement for an additional distribution system.
- Application of untreated wastewater as irrigation water or as injected recharge water may result in groundwater contamination.

In 1968, the first population census undertaken on Abu Dhabi Island counted only 22,000 people. About two thirds of the houses and establishments were served by simple septic tanks with soak-aways. These proved to be highly problematical due to a very shallow water table which led to local drainage problems, especially in winter when levels rose. The receiving station also had problems with flushing tank maintenance so that the flushing tanks were abandoned and the treated effluent began to be used directly for landscape irrigation on the island.

Rapidly increasing populations compounded the problem. Water borne diseases in Abu Dhabi at this time were typhoid, paratyphoid, dysentery and hepatitis. In order to protect the citizens from these potential health hazards and possible malaria, since the causative organism relies on large bodies of stagnant water, and because sewage flooding became more common, leading to higher risks associated with public health, the government gave great priority to improve the sewerage and drainage systems and it was quickly decided that the only solution was a piped sewage network and treatment facility. The first wastewater treatment plant (WWTP) was constructed on Abu Dhabi Island in 1973 with a capacity of 1.5 MIGD serving a population of 30,000. Immediately, the plant became over-loaded.

Figure 41a: Treatment of treated wastewater.

In 1975, the Sewerage Projects Committee (SPC) for Abu Dhabi Municipality was established with the responsibility of "providing a modern, efficient, well-constructed sewerage system for the collection, conveyance and treatment of all wastewater. The operation and maintenance of this system was designed to cause the least inconvenience to the general public and to treat the sewage so that the effluent and sludge could be utilized with minimum risk to public health" (Al Mazroui, 2000).

In 2005, the management of all STPs became the responsibility of the newly formed Abu Dhabi Sewage Services Company (ADSSC), under the regulatory control of the Abu Dhabi Regulation and Supervision Bureau, which is also responsible for regulating the potable water and electricity sectors.

In August 2007, the executive council formed a high committee to develop a strategy to increase the reuse of treated waster and biosolids in public gardens to minimize the use of fresh desalinated water and groundwater. The first meetings for this committee was in August 28th, 2007 at EAD headquarter office in Abu Dhabi. The outcome from this meeting was to form a technical committee with various representatives from the interested institutions including EAD, Municipalities (Abu Dhabi, Al Ain, and Western Region), ADSSC, SRB, and PGD.

c) Existing Treatment Systems

The Emirate has continued with its development of excellent waste – water treatment facilities. There are now 28 sewage treatment plants in the Emirate (STP), split equally between the Western and Eastern regions. Combined, they produce about 150 Mm^3 /yr (4.8% of total water demands). The Al Ain Al Zakher and Abu Dhabi Mafraq plants produce 95% of all treated effluent, which is mostly used for irrigation of parks, gardens and other recreation amenity areas. The other STPs are quite small, but because of remote urban expansion, some are now over-loaded and are presently being prepared for upgrading as shown in Figure (42).

Figure 42: Location of wastewater treatment plants in Abu Dhabi Emirate.

d) Domestic Wastewater Production and Reuse

Current per capita domestic water consumption in the Emirate is about double that of developed nations in Europe and according to ADWEA is 350 l/c/d. This generates a lot of wastewater which is distributed to treatment plants generally within or close to the sources of waste, with the exception of the Mafraq plant, which is located 40 km away from Abu Dhabi city which supplies it.

In the western region, the development of modern day sewerage infrastructure began in 1975 when H.H Sheikh Suroor bin Mohammed Al Nahayan was appointed as chairman of the Abu Dhabi SPC, responsible for management of the collection, treatment and re-use of sewage effluents. In 1975, the population of Abu Dhabi city was 93000, but, in the same year, a Sewage Master Plan was prepared for a total population of 665,000, out of them 500,000 were expected to reside on Abu Dhabi Island and the remainder on adjacent mainland developments such as Mussafah, Bani Yas and Al Wathba, not too dissimilar to present day conditions, with the exception of the additional new residential zones at Khalifa cities A and B. In 1975, it was Mafraq, not Mussafah, that was chosen for the main treatment plant site for Abu Dhabi city and construction work commenced in 1977 and the plant was commissioned in 1982. During the same year, heavy flooding in Abu Dhabi city, caused by very high rainfall, prompted the SPC to prepare an additional Master Plan for storm-water drainage, applicable to Abu Dhabi Island, Shahama, Mussafah, Bani Yas and Khalifa cities A and B. Although wastewater reclamation and reuse has been recognized as a promising strategy to alleviating water scarcity and reducing the impacts on the environment, the actual reuse of treated wastewater is rather limited. In Abu Dhabi Emirate only 56.3% of the total treated quantities are reused and the rest are disposed to the Arabian Gulf (ADSSC). Increasing the reused volumes will relief the pressure in using costly desalinated water and the over-abstracted brackish groundwater.

Due to the increasing number and size of developmental and industrial projects planned in the emirate of Abu Dhabi, an increase in the demand for sewage treatment plants is expected. The main sewage treatment plants currently operating in the emirate of Abu Dhabi are heavily overloaded, leading to the generation of low quality treated effluent. Furthermore, the overload could result in disposal of raw sewage in the marine environment and/

or desert. During emergency situations in the sewage treatment plant, more than 25% of the raw sewage inflow is diverted to the marine environment creating environmental crisis to marine quality and ecology. The Discharge point of excess treated effluent and over flow line is located at the Musaffah Industrial Area south channel.

The largest plant in the western region is located at Mafraq. This plant, along with the main Al Ain city plant, caters to about 65% of the total Emirates population. The installed capacity of the Mafraq plant is 260,000 m^3/d, equivalent to a serviced population of 725,000 persons. The plant uses anaerobic digesters (Figure 43) and the activated sludge method of treatment to the tertiary level where the final effluent is filtered through a sand medium to remove fine solids and uses chlorine to disinfect and kill micro-organisms. Abu Dhabi Island comprises about 1000 km of gravity sewers and is irrigated by about 180 km of pipelines supplied by 70 separate reservoirs. There are fifteen operating WWTP's in the eastern Region, the largest, plant being STP-M4 at Al Zakher, Al Ain and accounts for 92 % of the total production; the other fourteen plants are very small by comparison and service small towns and villages.

In the city of Al Ain, the administrative capital of the Eastern Region, sewage and drainage collection and treatment systems have been developed mostly in two main phases, 1981 and 1990-1995. By 1995, up to 250,000 people were served with a capacity of 27,000 m^3/d, and this was planned to be expanded to a capacity of 45,000 m^3/d, catering for an Al Ain regional population of about 420,000 people (present day situation). The plant produces treated effluent to tertiary levels and the salinity of the output varies between 1200 to 1490 mg/l TDS. Table (17) shows the total treated wastewater production in Abu Dhabi Emirate whilist Table (18) shows the small STP in the Western Region (KEO International Consultants, 2006).

Table 17: Treated Wastewater Production in Abu Dhabi Emirate

	Sewage Treatment Plant	Production, Mm3/yr
Eastern Region:	AL AIN STP-M4 (AL ZAKHER)	28.76
	Al Khazna WWTP	0.27
	Al Hayer WWTP	0.438
	Sweihan WWTP	0.248
	Shuwaib	0.310
	Seih Gharaba	0.020
	Wadi Flaie WWTP	0.266
	Al Quo'a WWTP	0.383
	Al Wagan WWTP	0.365
	Al Faqah WWTP	0.090
	Al Dhahira WWTP	0.098
	Seih Geheriba WWTP	0.014
	Remah WWTP	0.146
	Bu karriyyah WWTP	0.091
	Al Araad	0.020
	Al Sa'a	Under construction
	Total	**31.519**
Western Region:	Mafraq	113.51
	Madinat Zayed	1.793
	Bainoona	0.239
	Mirfa	1.079
	Canning factory Mirfa	0.083
	Ghayathi Ww T Plant	0.462
	Delma Island	0.324
	Al Khatim	0.116
	Ghantoot	0.171
	Sir Bani Yas Island	0.082
	Abu Al Abyad Island	0.082
	Liwa	Under construction
	Baaya-Sila	0.372
	Ghuwaifat	0.060
	Total	**118.373**
Total Treated Wastewater Production		**149.89**

Source: *EAD water statistics 2006.*

Figure 43: Intake (a) aeration (b) and secondary (c) settlement tanks at Mafraq wastewater treatment plant, Abu Dhabi

(a) (b (c)

Development of sewage treatment facilities at the smaller towns has occurred over the last five years or so; at Al Faqa, a plant to cater fro 4,000 people with a capacity of 700 m³/d was completed in the year 2001 and all produced water is used for roadside irrigation of trees. The utilization of the treated effluent will be discussed in detail in section 6.1.4, but is largely used for irrigation of parks, gardens and recreation facilities, and to a much smaller degree, irrigation of fodder crops.

Table 18: Small STP in the Western Region (KEO International Consultants, 2006).

Plant	Total length Sewers (km)	Irrigation Pipelines (km)	No. Pump Stations	Capacity (m³/d)
Bainoona	10.9	6.2	2	2,400
Madinat Zayed	152.7	29.03	9	14,800
Mirfa	28.4	22.9	9	6,000
Delma Island	41.2	11.9	9	6,500
Ghayathi	56.3	13.6	11	2,500
Baaya – Sila & Guwaifat	58.3	13.3	8	2,745
Liwa	40.6	5.2	1	2,500
Sir Baniyas Island	5.5	0.6	0	355
Abu Al Abyad Island	4.1	1	0	195

e) Industrial Wastewater Production

Industrial wastewater is treated by the following means:

- Along with domestic waste as part of cities distributed sewers
- In purpose built Industrial zone / Estate sewage systems
- In site specific factory's STP e.g. Al Ain Dairy Farm

In the first case, large volumes of industrial waste are fed into distributed sewer mains, especially in Abu Dhabi from the Mussafah Industrial Complex, causing the wastewaters to be high in pollutants and trace metals. Considerable expansions of the Industrial estates at Abu Dhabi (Abu Dhabi Industrial City – Mussafah) and Al Ain are planned with maximum daily sewage outflows of 58,000 m³/d and 21,000 m³/d respectively.

The ADNOC Group, encompassing seventeen large industrial companies, have developed comprehensive and up to date wastewater collection and treatment facilities at all their operations both onshore and offshore Abu Dhabi. The Takreer Company has developed a Centralised Environment Protection facility including wastewater treatment plants. At the ADNOC Ruwais Industrial estate housing complex two million cubic meters of raw sewage was treated in 2004 providing for 1.4 million m³, secondary treated effluent for exclusive use in the irrigation of landscaping in the area of the Ruwais complex. The treatment is accomplished using the twin single sludge anoxic/aerobic dispersed growth biological treatment process for total Nitrogen and Biological Oxygen Demand (BOD) 5 removal. Both plants have a combined capacity of 8785 m³/d.

Other ADNOC group wastewater facilities include the following:

- ADCO – 12 onshore camps use biological filtration/ chlorination sewage treatment plants.
- Bourouge – treat 48 m³/d raw sewage.
- NDC – have 16 rigs (38 m³/d sewage output and Bu Hasa base camp (11 m³/d sewage output) using biological methods of treatment.
- Abu Dhabi National Tanker Company operates 8 ships, all with their independent on board STP, each producing 85-90 m³/month raw sewage which is

treated for discharge to sea.

- GASCO-uses chemical methods to treat about 800 m^3/d for use in irrigation.

- Bunduq – all offshore platforms produced 4212 m^3 in 2004 which was treated by physical and chemical means for discharge to the sea.

- IRSHAD – operate STP on offshore Islands of Mubarraz and Das, the latter producing 1350 m^3/d of raw sewage, 52 % is recoverable using the tertiary biological method with aeration tanks and bacteria, for use in irrigation.

More recently, other STP have been commissioned at the sites of individual factories. In 2001, the construction and commissioning of a new sewage and wastewater treatment plant for Marmum Farm at the Al Ain dairy factory was specially developed to meet the requirement that all wastewater be treated to a standard suitable for horticultural use at the farm. Special processing systems were installed to ensure that water was suitable for the development of a green zone around the farm and encourage the cultivation of fodder for the cattle and for the planting of trees and other flora. A system was installed that would handle all the wastewater generated from the cow sheds, milking parlours and milk handling facilities at the farm. The waste water is then taken through a series of processes before finally being disinfected and filtered, leaving water suitable for horticultural applications.

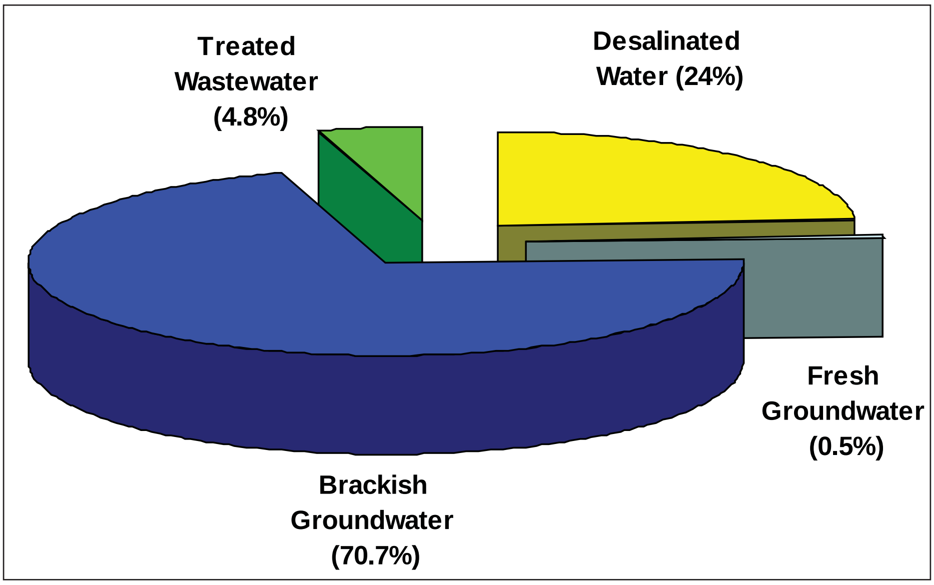
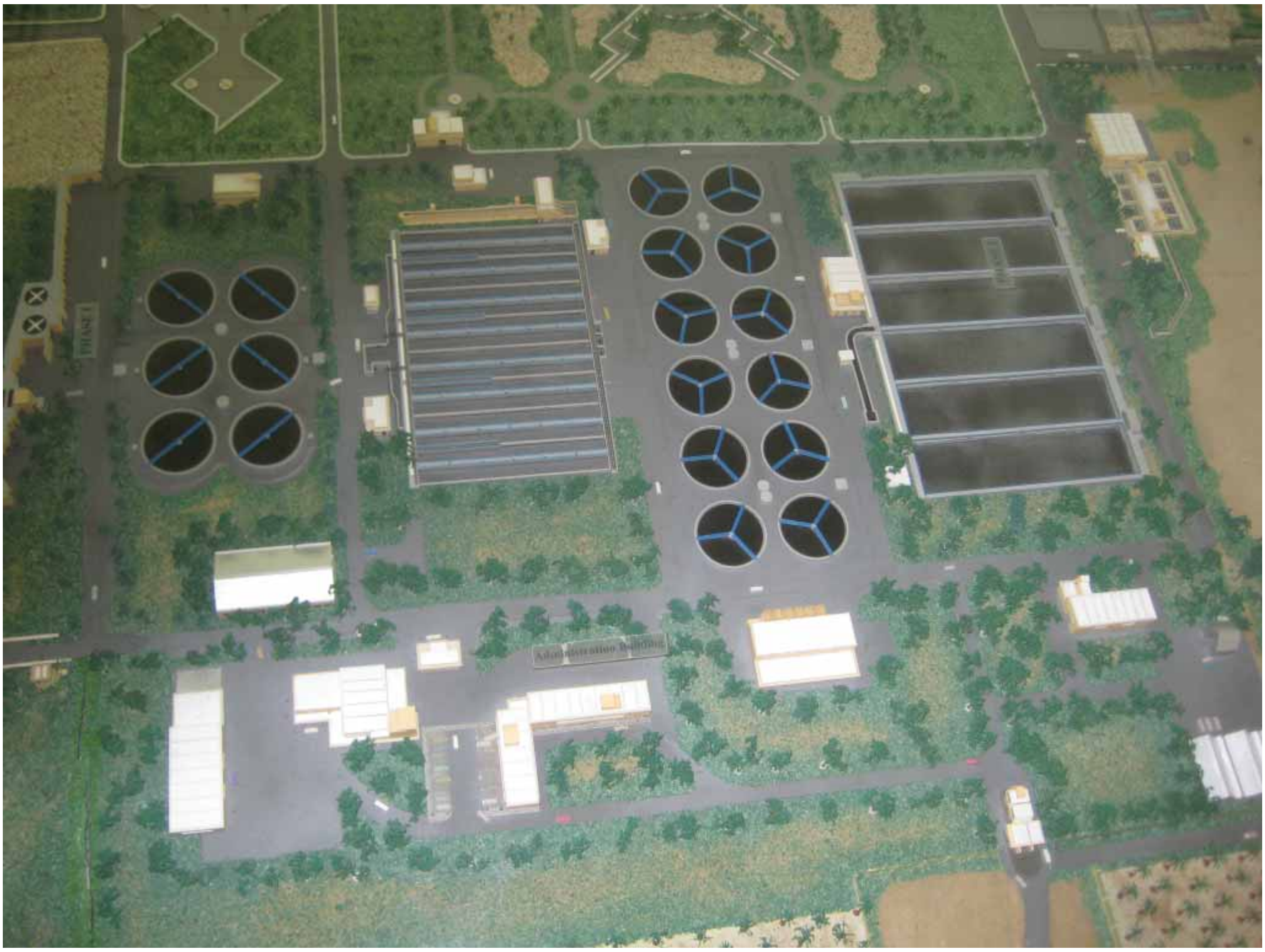


Figure 44: 2007 Water Resources by Source.



Al Mafraq Wastewater Treatment Plant in Abu Dhabi Emirate.

6 Water Demand and Use

6.1 Present Water Demand and Use

Irrigation in the agriculture, forestry and amenity plantation sectors accounts for a massive 76% of the total Emirate water use, the remainder is taken up with domestic and industrial consumption, both of which is supplied in bulk by the Abu Dhabi Water and Electricity Authority (ADWEA). Table (19) summarizes the total water consumption for the year 2006 and Figure (45) shows the water consumption in Abu Dhabi Emirate by water user sector.

Total water used in 2006 is about 8% less than that used in 2003; this is brought about by a corresponding 18% reduction in groundwater used due to aquifer depletion under a general regime of unsustainable development.

Table 19: Total water consumption per sector (2006).

	EAST		WEST		TOTAL		% Change - 2003/2006
	(Mm3)	%	(Mm3)	%	(Mm3)	%	%
Domestic	111.53	3.57	607.06	19.44	718.59	23.01	**37.7**
Industry	9.48	0.30	58.26	1.87	67.74	2.17	**16.8**
Agriculture	979.80	31.37	761.59	24.38	1741.39	55.75	**-10.7**
Forestry	124.98	4.00	237.40	7.60	362.38	11.60	**-40.3**
Amenity	107.16	3.43	126.04	4.04	233.20	7.47	**-4.8**
TOTAL	1332.95	42.68	1790.35	57.32	3123.30	100.00	**-7.6**
						3123.30	**-7.6**

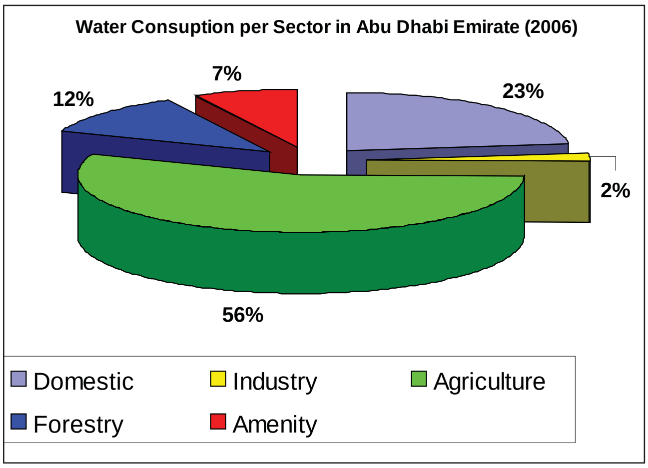


Figure 45: Water Consumption by Sector (2006).

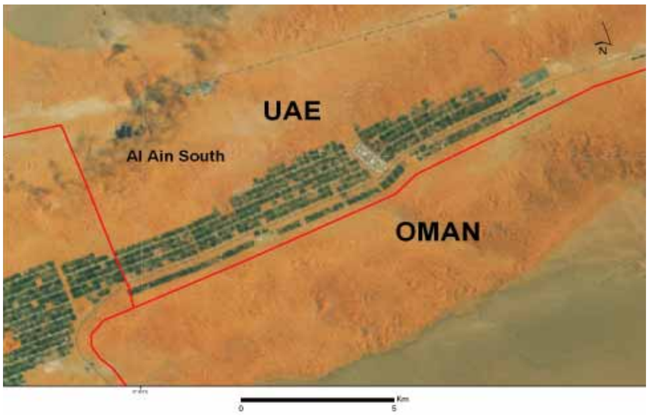


Figure 46: Citizen's Farms in the Al Dahira area Eastern Region

Figure 47: Forestry in the Eastern region

6.1.1 Domestic Sector

Water demand in this sector includes domestic and bulk categories. Domestic water demand includes mainly residential, commercial establishments, hospitals, hotels, offices, and shops. Bulk water demand includes agriculture, landscaping, large industrial usage, palaces, airports, and other non-domestic bulk diversions. The significant increase in customer demand for water occurred mainly in government sponsored housing development schemes and agricultural activities; particularly in the farming and forestry sectors.

In 2003, 15.5% (580 Mm^3) of all water consumed in Abu Dhabi Emirate was in the domestic sector; 96% from desalination, 4% only from groundwater wellfields. All of the 16 producing wellfields as shown in Figure (48), containing 600 wells, of which 333 only are operated, are located in the eastern region. In 2002; wellfields in the Liwa area of the western region were discontinued for domestic supply due to water quality difficulties. Table (20) shows a classification of the eastern region wellfields based on groundwater salinity.

The Taweelah plant is currently the largest Distillation (MED) plant in the world (0.25 Mm^3/d) and a new Reverse Osmosis (RO) plant under construction will also be the largest in the world at 0.25 Mm^3/d. The new Shuweihat plant has the largest Multi Stage Flash (MSF) units in the world, each capable of 80,000 m^3/d.

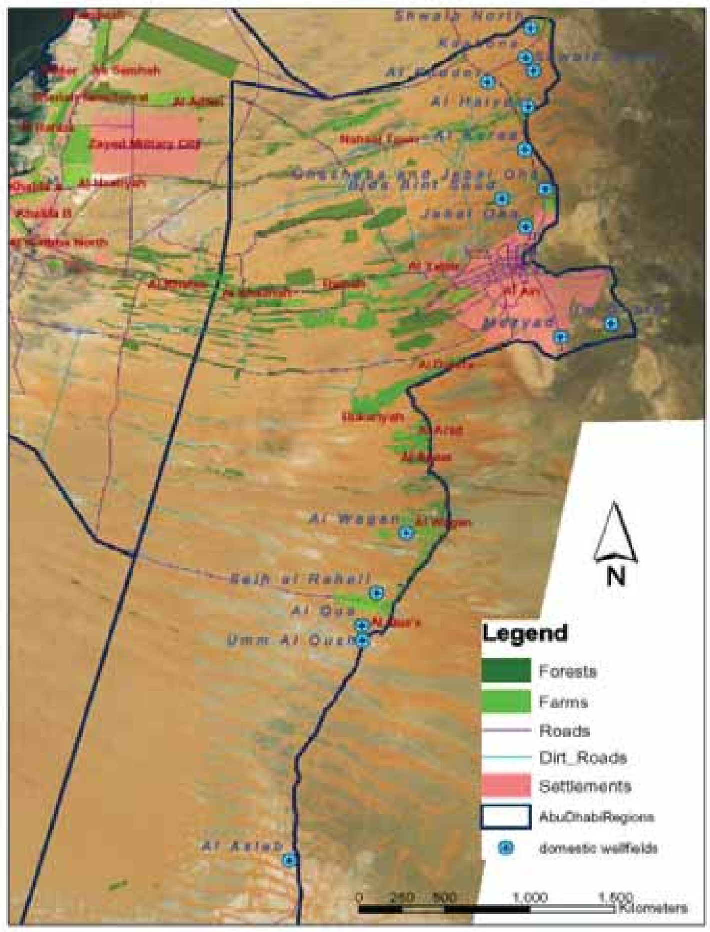


Figure 48: Municipal wellfields in the Eastern Region

Previously, all of Al Ain city's domestic water requirements were met from wellfields, however, massive increases in domestic demands, from an annual population growth rate of 8 %, has meant that wellfields have been placed under increasing stress, resulting in declining water levels, increase in groundwater salinity with a resultant decrease in total production.

The widening gap between groundwater supply and domestic demand has been met from an expansionist policy of desalination using all types of production process under an ever increasing responsibility of the private sector. The United Arab Emirates, Abu Dhabi Emirate in particular, is now a world leader in the application of desalination technology. The present trends of development are individual plant scale increases coupled with unit capacity increase. The current costs of production are around \$0.7 /m³ with a short term goal to achieve \$0.5/ m³. The Taweelah A1 plant is currently the largest Multi Effect Distillation plant.

Table 20: Classification of the Eastern Region Domestic Supply Wellfields.

Wellfield Name	Water Quality Classification	% Total 2002 Production
Shuwaib South, Al Haiyer, Al Karaa, Ghashaba, Al Zaroub, Kashona, Umm Ghafa	Fresh	64
Shuwaib North, Al Khadar, Bida bint Saud, Al Ashoosh, Jebel Oha, Al Wagan, Al Qua, Seih Al Raheel	Low Brackish	35
Al Aslab	High Brackish	1

Note: *Fresh 0-1500 mg/l TDS, Low Brackish 1500–8000 TDS, High Brackish 8000–15,000 TDS.*

In 2005, the total domestic wellfield production had reduced to only 10 Mm³/yr, meeting only a fraction of the total domestic requirements in the eastern region. Since 1998, production from the domestic wellfields has decreased by over 85% as shown in Figure (49). Table (20) shows that a large proportion of abstracted groundwater no longer meets the Abu Dhabi drinking water standard (RSB, 2004b) and this challenge has been met by blending indigenous, brackish groundwater with imported desalinated water from the Arabian Gulf and, more recently, from the Gulf of Oman at Qidfa, Al Fujairah. Despite their costly operation for a relatively small to moderate production, the wellfields continue to operate and are strategically important as an emergency back up to any potential failure in the supply of imported desalinated water to the eastern region. The protection of the wellfields, especially those in active recharge zones and which still produce fresh water, is a priority and appropriate wellfield protection zones need to be demarcated and enforced. The balance of domestic demand in the eastern region and also the full requirements for the western region, are now met by desalinated water.

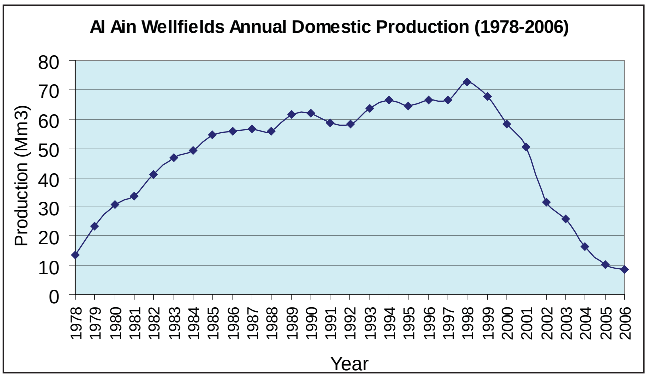


Figure 49: Al Ain wellfields total production (1978 – 2006).

The provision of desalinated water supply has been well planned, but extremely costly, however supply has always kept abreast of demands. Excess capacity at present provides a potential resource for artificial recharge of aquifers utilizing Aquifer Storage and Recovery (ASR); a relatively new concept for this region (first proposed in 1993), which is currently being tested at the pilot test study level in the Eastern and Western Regions of the Emirate. Figure (50) shows the expansion of the desalination industry in Abu Dhabi Emirate between 1990 and 2006. In 2006, six desalination companies had a combined capacity of 746 Mm^3/yr.

An ownership and regulation re-structuring of the Abu Dhabi Water and Electricity Authority (ADWEA) in 1999 has resulted in the following:

- Four power generation and desalination companies.
- A ‘single buyer’ company (ADWEC).
- Abu Dhabi Transmission and Dispatch Company (TRANSCO) for water transmission.
- Two Water Distribution Companies, one for Abu Dhabi and one for Al Ain.
- Abu Dhabi Company for servicing Remote Areas (ADCSRA).
- Four Independent Water Producers.

The re-structuring has increased the efficiency of operation and reduced the costs to government by allowing up to 40 % private foreign investment in the independent water producing companies. The entire water industry is now regulated by the independent Regulation and Supervision Bureau, established in 1998, providing for company licensing and also the protection of the interests of water consumers. Comprehensive water supply - demand planning is carried out by ADWEC over 7-year planning horizons. ADWEC have also published their expected desalination programme until the year 2015 (ADWEC, 2005).

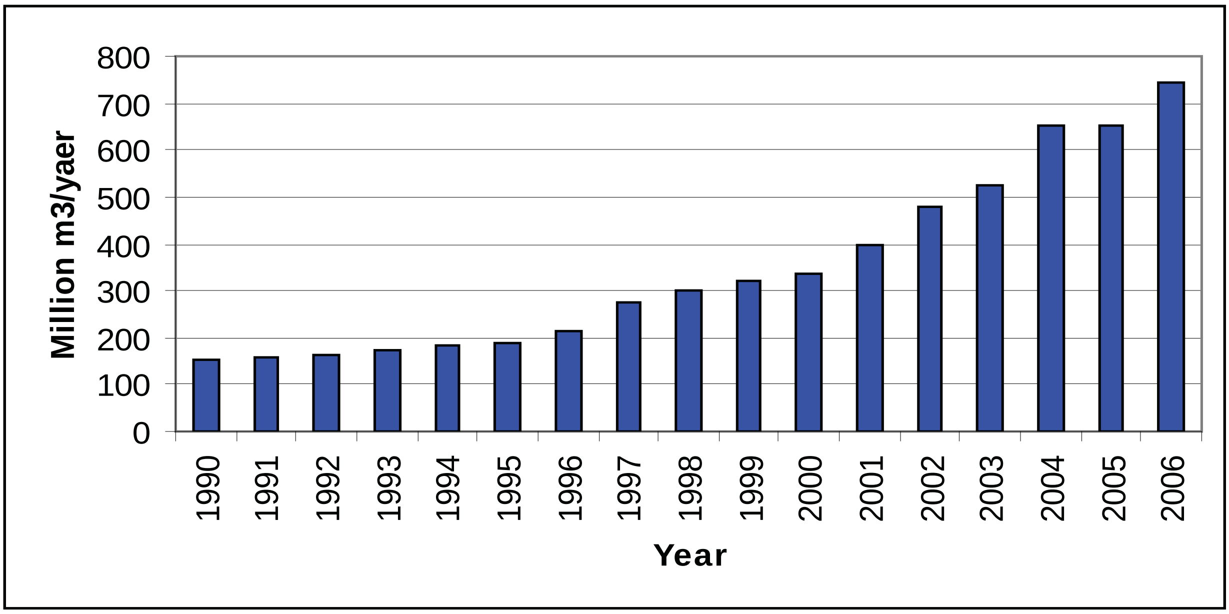


Figure 50: Annual desalination production in Abu Dhabi Emirate (1990-2006).

Network Losses

There is little non-propriety information available about the efficiency of the water distribution system and the volumes of water lost. No matter how well designed and managed, water distribution systems leak. In well-managed and maintained systems leakage may be as small as 10%; in poorly maintained systems it may approach 50%. Knowing how much is lost is important because it represents expensive energy and water that is wasted and lost revenue to the bulk supplier and retailer.

According to ADWEA water 'production' by the desalination plants was almost equal to bulk water supplied to the water distribution companies. In 1999 it was 96% of 'production' and increased to 99% in 2006. In contrast the ratio of bulk water supplied to the distribution companies to installed desalination capacity has averaged 75% over the period 1998-2006, Table (21). Most of the losses will accrue to storage in the shallow groundwater reservoir. The interaction of the water losses from the domestic and industrial water distribution system with local ecosystems is also unknown.

How much of the difference between installed capacity and water supplied to distribution companies is actually lost is unknown. It is certainly not zero. Water is distributed by TRANSCO through over 2,000 km of pipeline (ranging in diameter from 500 to 1600 mm) at quite high pressure. North of Abu Dhabi, for example, an area of wetland has become established and appears to be sustained by leakage from the water transmission network. Conservatively it may be put at 10-15% - or near the global average considering normal leakage under high pressure and water in the system that is lost during maintenance activities. In 2006 the difference between installed capacity and delivery to distributors was 313 Mcm/year or 27% of the potential supply. At 15% water losses in the main system would be 174 Mcm/year potentially representing US$57 million in lost revenues plus greenhouse gas emissions that were not necessary. Actual losses would be higher if the level of subsidy at economic prices could be taken into account.

Table 21: Calculation of Losses in Water Distribution Network (Mcm/year)

Item	1998	1999	2000	2001	2002	2003	2004	2005	2006
Desalination Capacity	352	377	428	540	745	745	913	1,082	1,109
Total Water Production	303	322	345	395	480	547	629	742	802
Received by Suppliers	261	311	340	390	474	542	623	734	795
Utilization of capacity	86%	86%	81%	73%	64%	73%	69%	69%	72%

Source: *ADWEA 2008*

Potential Losses from the Suppliers Distribution Systems

The information available is not complete. The Abu Dhabi Distribution Company (ADDC) produces annual reports while none is available from the Al Ain Distribution Company (AACD). The ADDC manages an extensive distribution system that connects more than 171,000 customers through a pipe network of more than 6,100 km covering 86 zones. The latest (2006) ADDC Annual reports that network coverage is increasing at 10% a year. Breakage of pipes accounted for over half (54%) of customer complaints. Even so, on the basis of international comparators supply outages from breaks in the supply network were only two-thirds of international norms (0.03 breaks/km). Apart from good maintenance this also reflects the relative newness of the system. Despite this ADDC, management acknowledges that leakage remains a problem and a leakage management strategy was initiated in 2006. Actual rates of Unaccounted for Water (UfW) that includes leakage are unknown. However, it has been possible to make an estimate of UfW for 2006 from data published by ADWEA and RSB, Table (22). On this basis UfW is about 51%. How this is split among leakage, non-billing or theft is unknown. Although the figures for the total water demand from the domestic and industrial sectors are well defined and are mostly based on metered flows, this is not true for the agricultural, forestry and amenity sectors.

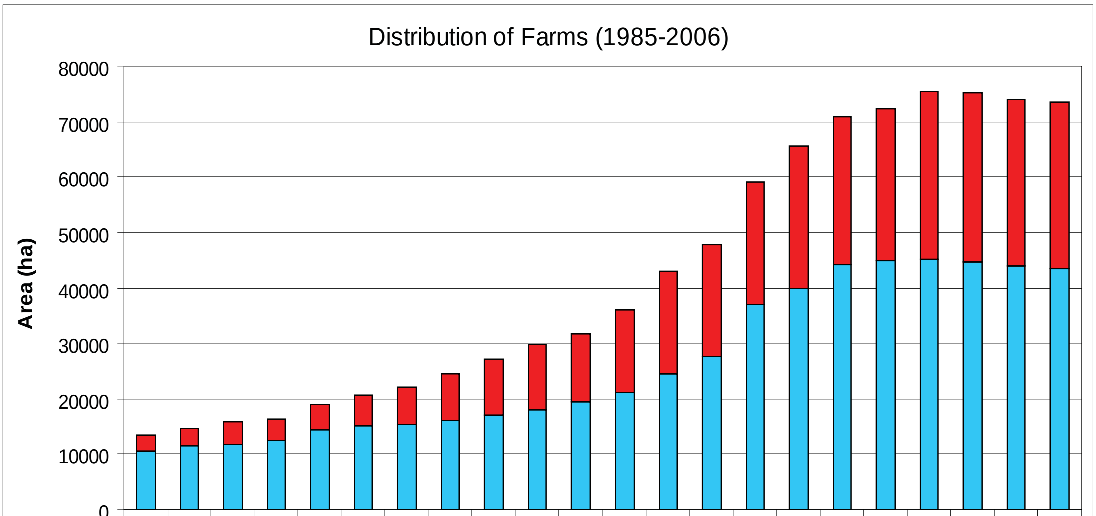
Table 22: Estimated levels of Unaccounted for Water by the Distribution Companies.

Item	Volume (Mcm)
Desalination Capacity	1,109
Desalinated 'Production'	802
Total Bulk Water sold by TRANSCO (A)	795
Water received by ADDC	296
Water received by AADC	95
Total water retailed by the Delivery Companies (B)	391
Bulk Sales/Retailed (A/B)	49%

Source: *Bulk volumes from ADWEA Water Statistics 2008. Retailed volumes form 2005 Price Control Review (page 27) by the Regulation and Supervision Bureau.*

6.1.2 Agricultural Sector

This sector consumes 58 % (1949 Mm^3/yr) of all of Abu Dhabi Emirates demands. By the end of 2003, there were about 25,000 citizen's farms, occupying around 75,500 ha and a small number of large, state fodder (government) farms occupying about 17,000 ha. Figure (51) shows the expansion in agriculture due to large government support. Citizens farms are typically 2-3 ha in size and each have two drilled wells at opposite corners of the plot. A well supported system of subsidies promotes agricultural expansion to the tune of 3,000 new farms each year, although expansion is currently restricted due to exhaustion of groundwater supplies. The type of crops grown are based on recommendations provided to the farmers from the Agriculture Extension Services Department belonging to the municipality and agriculture sections in the western and eastern regions of the Emirate. Figure (52) shows a map of all agriculture developments in Abu Dhabi Emirate.



	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1965	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Western Region	2802	3161	3937	4045	4494	5667	6722	8382	10046	11708	12143	14874	18393	20036	22016	25935	26792	27331	30378	30378	30087	30054
Eastern Region	10624	11568	11811	12403	14397	15107	15331	16199	17036	18116	19512	21135	24532	27725	36986	39768	44103	44946	45072	44761	43882	43500

Figure 51: Expansions of Citizens' Farms 1985 to 2006.

The major limitations on agricultural development are lack of groundwater resources and high groundwater salinity used in irrigation. Figure (52) shows a landsat image of typical citizens farms developments; close proximity of wells to each other results in well interference effects and unrestricted irrigation causes extreme cones of depression causing a deterioration in salinities, which are usually low brackish to high brackish to begin with. For example, in citizens farms in the Al Ain region, irrigation water salinity exceeds 4000 mg/l [6000 μS/cm] in 65 percent of farms (ERWDA/MMI, 2004i).

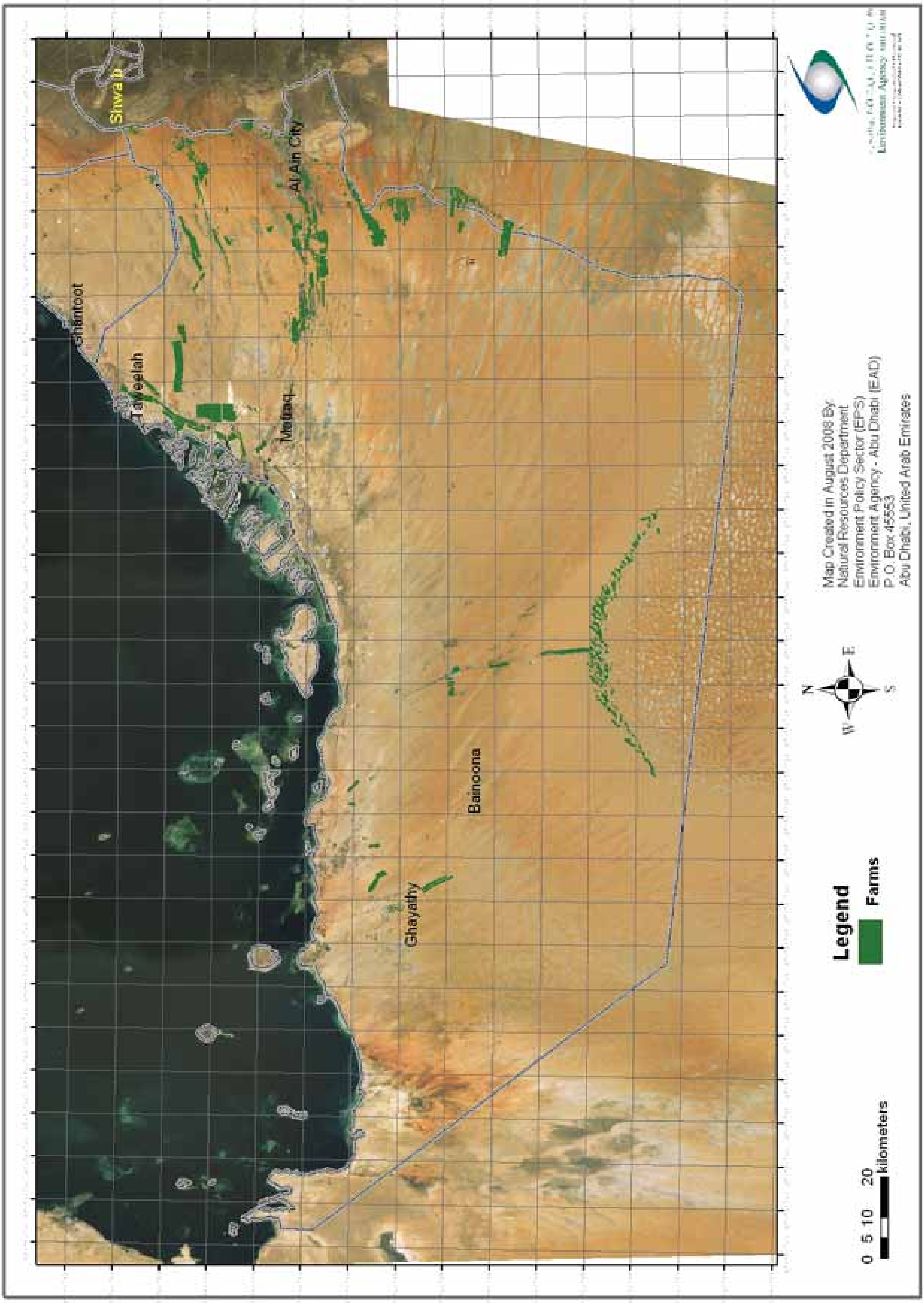


Figure 52: Agricultural developments in Abu Dhabi Emirate.

Agriculture is generally dominated by two perennial crops, Dates and Rhodes grass, with some seasonal plantings of short season annual vegetable crops; a limited area of cereals and fruits are also grown. Most agriculture is on small private farms that have been established in relatively recent times, but there are also small areas of traditional date palm gardens and larger government forage production units. There is also a limited area of protected horticulture (greenhouses, cloches etc).

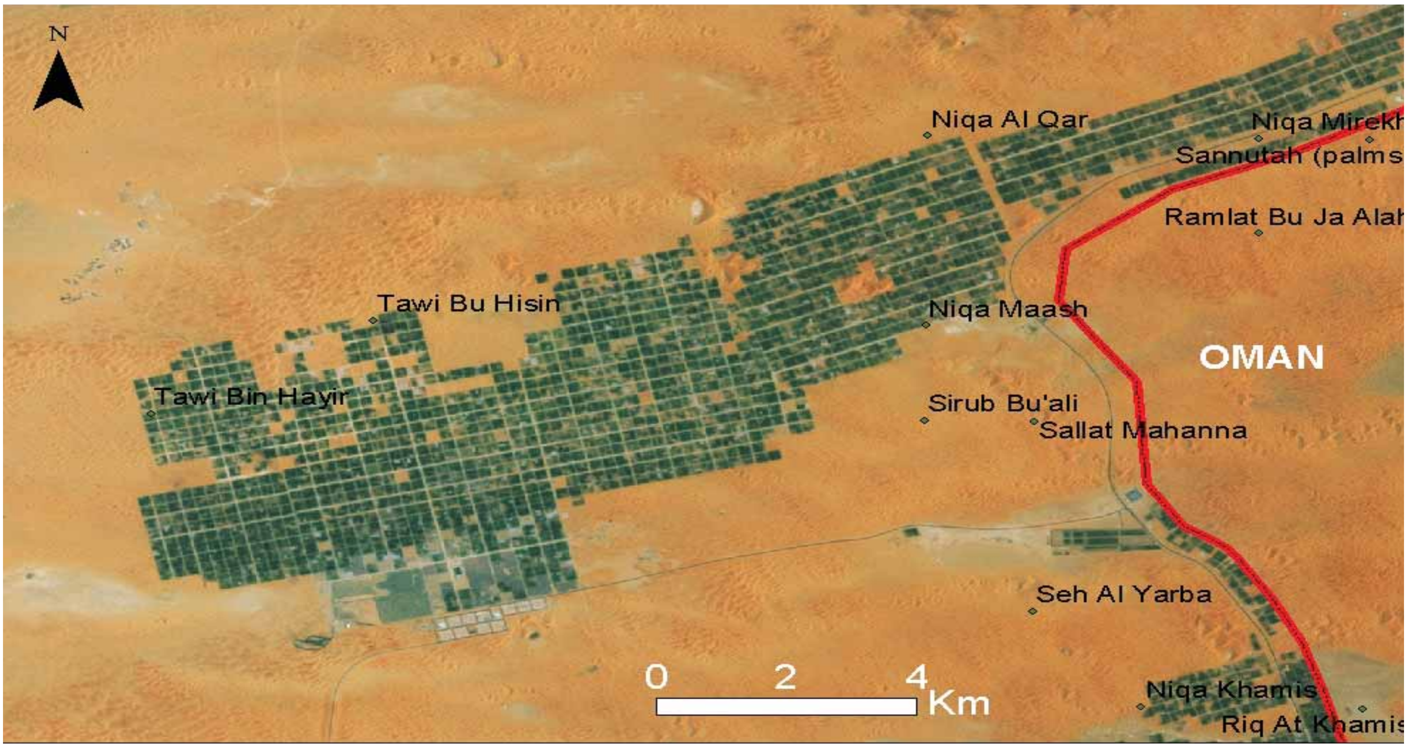


Figure 53: Typical Citizens Farms Development (2007).

6.1.3 Forestry Sector

This sector consumes 18% (607 Mm^3/yr) of all of Abu Dhabi Emirates demands. By the end of 2003, there were around 250 separate forestry plantations, under the management of the Al Ain Forestry Department and the Abu Dhabi Municipality Forestry section as shown in Figure (54). In 2005 it was decided to outsource the operation and maintenance of these forests to private sector. Expansion in the sector in the eastern region has been rapid and is shown in Figure (55). Figure 55 shows the distribution of the forests within the whole Emirate. A total 58,000 hectares of development was recorded in 1989; the total area under cultivation is now 305243 hectares, representing an expansion of 26 % per annum. Individual plantation sizes range from 4 to 70,000 hectares and 80% of development is located in the western region. A total of 64 million trees are irrigated by 5,713 wells. In the eastern region, 12264320 trees, occupying 56854 ha, are irrigated with 122.85 Mm^3/yr. In the western region, 51317276 trees, occupying 243494 ha, are irrigated with 484.45 Mm^3/yr. Tables (23) and (24) show details of all the individual forests in both the eastern and western regions respectively.

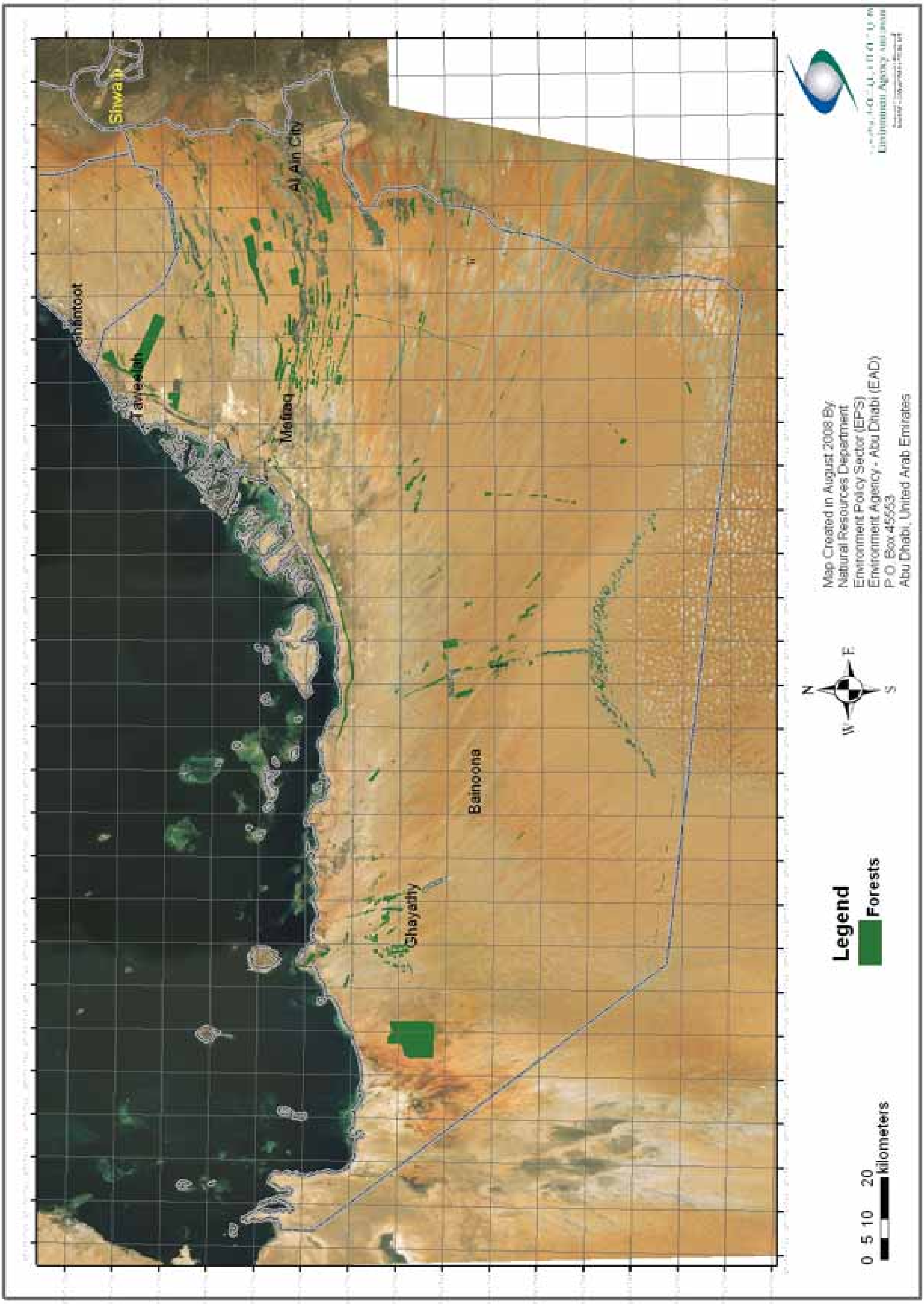


Figure 54: Location of forests within Abu Dhabi Emirate.

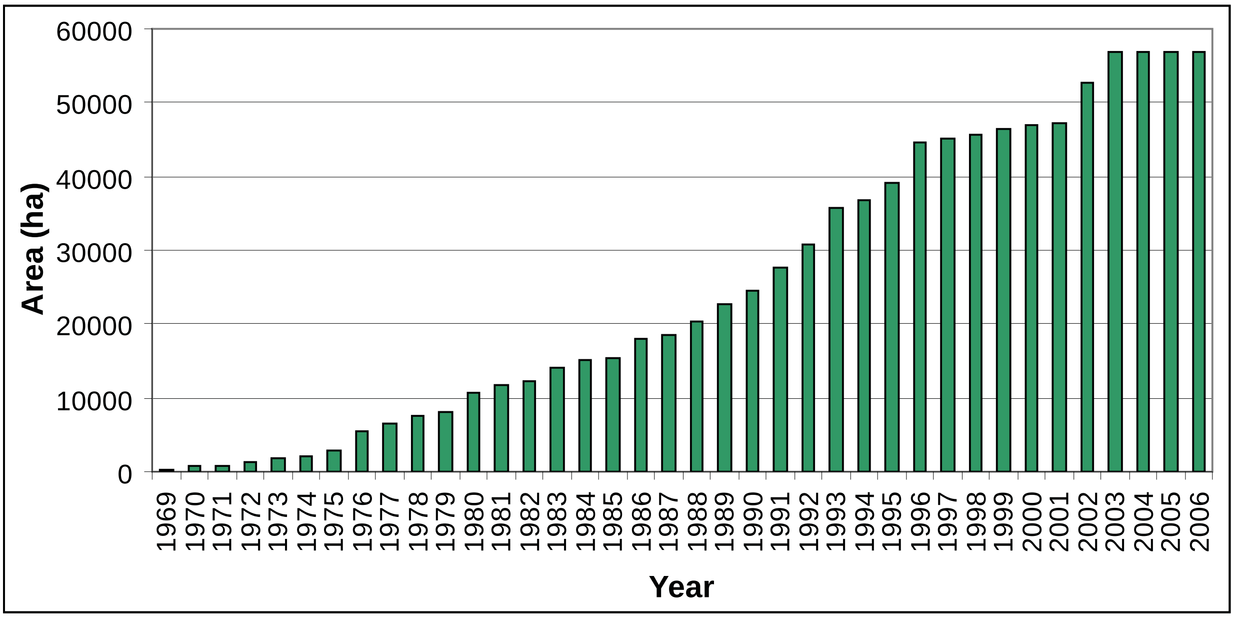


Figure 55: Forestry Expansion in the Eastern Region of Abu Dhabi Emirate.

The objectives of the forests are to protect roads from sand incursions, especially in areas of high dunes, sand dune stabilization in areas of existing developments, providing protected areas for wildlife sanctuary and, more recently, demarcating UAE's international boundaries with its neighbours.

All forestry is irrigated by groundwater; recently, there is a development to supply limited desalinated water to some projects in the western region. This sector is faced with operational challenges related to poor water quality, lack of sufficient quantity of irrigated water and also poor quality soils.

Groundwater used for irrigation ranges in quality from 4,200- 40,000 mg/l. Acceptable tree growth can be managed with groundwater of 7,000 mg/l [10,500 μS/cm] but since the location of forest development is generally fixed by others, the Forestry Departments sometimes have to make do with water of salinity inimical to good tree growth; an example is Al Yaeela some 55km WSW of Al Wigan where groundwater salinity was too high (over 35,000 mg/l) for forest establishment to proceed.

In the western region, salinities of mostly over 10,000 mg/l and up to 40,000 mg/l are found; Forestry developments along the Abu Dhabi – Duabi highway are irrigated by fresh groundwater imported from Kashona wellfield in the eastern region and recently, desalinated water from Taweelah. Even with blending from these lower salinity sources, only rarely is water with a quality as good as 5000 mg/l used. Over 17,000 ha of forest developments exist along the Abu Dhabi- Dubai road. A 1000 ha forest in the Al Samha area uses desalinated water and in Al Shehamah forest, a mix of desalinated water and groundwater is used. Both groundwater quality and well yields are reported to be slowly deteriorating and increased use of desalinated water is foreseen.

Table 23: Forests in Eastern Region.

No.	English Name	Area (Hectar)	Num-ber of Wells	No.	English Name	Area (Hectar)	Num-ber of Wells
1	Swehain-1	300.0	27	41	Al Araqia-1	60.0	7
2	Swehain-2	400.0	29	42	Al Araqia-2	40.0	4
3	Swehain-3	300.0	27	43	Shaab Al Gaff	533.0	23
4	Swehain-4	300.0	23	44	Al Ojer	1444.0	117
5	Seah Al Malha	400.0	30	45	Seah Sahem	200.0	12
6	Seah Al Mishaab	400.0	25	46	Al Zaba (Old)	300.0	26
7	Gaff Rakdh Al Sharqi	400.0	18	47	Al Zaba (New)	300.0	25
8	Bu Harma	200.0	21	48	Al Gheena	300.0	28
9	Rakna	200.0	21	49	Al Wagan (Old)	950.0	55
10	Bida Bint Saud-1	600.0	35	50	Al Wagan (New)	672.0	72
11	Al Ashoosh	1260.0	142	51	Al Hamran	400.0	25
12	Wadi Al Jabeeb	50.0	7	52	Al Qua	250.0	24
13	Al Shuwaib	436.0	10	53	Umm Al Osh	190.0	4
14	Kashuna	40.0	4	54	Umm Al Osh	190.0	18
15	Al Hayer	20.0	3	55	Umm Al Banadiq	1350.0	96
16	Masakin	10.0	4	56	Bida Khalafan	775.3	62
17	Wadi Al Shuwaib	345.0	25	57	Al Jeteah (East)	300.0	37
18	Al Taweela	300.0		58	Al Jeteah (West)	400.0	40
19	Al Hayer Farm	500.0		59	Bil Hairan (Old)	400.0	45
20	Al Khazna	634.0	92	60	Sabkha Bil Hairan	400.0	40
21	Al Qattar	700.0	38	61	Naqahadfi	200.0	27
22	Mirameeth	400.0	62	62	Seah Nishash	640.0	1
23	Bida Al Dhawaher	591.0	70	63	Al Maqam	690.0	8
24	Bu Arta	2200.0	39	64	Al Roudha-3	400.0	22
25	Remah Forest	410.0	72	65	Seah Bin Ammar	285.0	13
26	Al Saad West	410.0	42	66	Al Yaeela	1100.0	130
27	Al Twaisa New	2674.0	43	67	Kharima Bil Haliwa	400.0	24
28	Al Taweela Old		32	68	Bida Harab	360.0	55
29	Air Port	411.0	38	69	Khor Bin Atyee	1500.0	86
30	Al Salamat	350.0	31	70	Gaswera	600.0	27
31	Al Lesaily	10000.0	220	71	Umm Al Zamool	50.0	6
32	Seah Sallam	2500.0	126	72	Bu Nakhaila	400.0	31
33	Bil Hawaiz	400.0	37	73	Al Zarwi	20.0	7
34	Seah Al Meah	1624.0	106	74	Nursery Bida Dhawaher	9.0	13
35	Al Saad-143	357.0	22	75	Nursery Al Salamat	4.0	6
36	Al Saad-145	100.0	6	76	Nursery 123	28.0	12
37	Aslab	873.0	20	77	Al Warsan Farm	1830.0	68
38	Helipad	20.0	6	78	Al Roudha West	2600.0	51
39	Al Hadood	20.0	4	79	Al Roudha East	2400.0	65
40	Jabal Hafeet	730.0	14	80	Ghamra	2000.0	36
	Total Area	49835	3019				

In order to optimize tree growth potential under these difficult conditions, emphasis has been placed on growing indigenous species as shown in Table (25), such as Prosopis cineraria (ghaf), Salvadora persica (tooth brush tree), etc. In the Eastern Region, these two species alone account for over 60% of all trees.

Table 24: Summary of forestry areas and well information in the Western Region.

Region	No. Wells	Well Depth Range (m)	Groundwater Salinity Range (mg/l)
Madinat Zayed	500	12-91	1500-18,000
Liwa*	143	15-91	800-13,000
Ghayahthi	392	13-46	4,000-15,000
Al Wathbah	1817	9-61	3,500-51,000

* Liwa falls in the Madinat Zayed Forest Administration Region

Table 25: Tree species grown in Abu Dhabi forest plantations (2007).

No.	Plant species	Local Name	Common Name	Max Salinity Tolerances (mg/l)
1	***Acacia ehrenbergiana*** Hayne	salam		7,000-8,500
2	***Acacia nilotica*** (L.)Delile	garath	arabian gum tree	8,000-10,000
3	***Acacia victoriae*** Benth.			8,000
4	***Acacia tortilis*** (Forssk.)Hayne	samar		2,500-6,000
5	***Acacia cyanophylla***			1,500-40,000
6	***Prosopis cineraria*** (L.) Druce	ghaf	umbrella thorn	8,000-14,000
7	***Prosopis juliflora*** (Sw.)DC.	ghawaif	Mesquite	35,000
8	***Prosopis chilensis*** (Molina)Stuntz			8,000-10,000
9	***Ziziphus spina- christi*** (L.) Willd.	sidr	jujube	4,500-5,500
10	***Salvadora persica*** L.	arakh	tooth brush tree	9,000-16,000
11	***Phoenix dactylifera*** L.	nakhil	date palm	25,000
12	***Eucalyptus camaldulensis*** Schlecht.	keena	eucalyptus	9,000-12,000
13	***Azadirachta indica*** (L.)	neem	neem tree	up to 8,000
14	***Cassia italica*** (Mill.) F.W. Andrews	senna		1,500-5,000
15	***Conocarpus lancifolius*** Engl	dammas	land mangrove	15,000-25,000
16	***Atriplex*** spp.	atriplex		8,000
17	***Haloxylon salicornicum*** (Moq.) Bunge ex Boiss.	rimth		8,000-10,000
18	***Simmondsia chinensis*** (Link.)C.K.	jojoba	goatnut	6,000-7,000
19	***Calligonum comosum*** L'Her.	arta		5,500-6,000
20	***Leptadenia pyrotechnica*** (Forssk.)	markh		4,500-5,500
21	***Haloxylon persicum*** Bunge	ghada		4,000-5,000
22	***Zygophyllum qatarense*** Hadidi	harm		32,000-35,000

6.1.4 Amenity Plantation Sector

Amenity irrigation for parks, gardens and recreational areas (e.g. golf courses, football pitches etc.) accounts for just over 7% of total consumption. This sector relies mostly on treated effluent as a source, but wells are also utilized, especially in Al Ain city, where over 400 wells have recently been inventoried. Treated effluent is also used for irrigation of small scale fodder farms. The area under amenity irrigation has increased rapidly with the growth in urban areas and the development of road systems throughout the Emirate. There are 85 parks and gardens occupying a total area of 951 ha. Other amenity plantings e.g. golf courses etc occupy a much larger total of 6617 ha. Combined, it is estimated that amenity plantations use about 245 Mm^3/yr of water, a combination of treated effluent, desalinated water and also local groundwater. Residential properties of the Dewan (palaces) are also included within this category of water use, although they use largely bulk supply from ADWEA.

Amenity plantings seem to receive near optimum amounts of irrigation water which is largely treated sewage effluent (TSE) of a consistent quality. A total of 131 Mm^3/yr treated (over 80 % to tertiary level) wastewater is produced from 25 operating plants; a further four are under construction. The largest sewage treatment plant is located at Mafraq, 40 km from Abu Dhabi city, which treats all domestic and industrial sewer mains waste for Abu Dhabi Island and surroundings, catering for a population in excess of 500,000. Generally, a large proportion of all domestic and industrial wastewater is treated and re-used, but this forms only about 4% of all water produced. Abu Dhabi Emirate has an excellent record for water recycling and there is currently no surplus capacity for wastewater. Sewage treatment expansions are ongoing at Abu Dhabi and Al Ain cities, but it is anticipated that, given increasing pressures to develop more recreation areas for an expanding population, increasing reliance will need to be placed on desalination for meeting requirements.

For the Al Ain area, a recent study (Branke, 2005) has re-mapped amenity areas to include roadside plantings, public parks, palace gardens, plantings at other public facilities e.g. Al Ain Zoo and several hotel garden areas, for a total area of 6689 ha. Figure (56) shows part of Al Ain after re-mapping was undertaken.

Total water demand for afforested areas may be overestimated. Not all seedlings planted reach maturity. And unless the trees receive adequate irrigation and water quality they may stunt and die– most trees are fed with brackish water. Trickle irrigation with poor quality water also creates problems because removal of chemical deposition that clogs the drip orifice requires regular maintenance. Recent research by EAD (Brook 2004) indicates that “the majority of trees receive under-irrigation [that] will lead to the development of reduced canopies: no forest have been observed which have a full canopy, which indicates that they are young stands or that they have been under-irrigated and their growth restricted.” Given that aforestation started four decades ago this is surprising.

Determination of the actual area of forest and its water use need considerably more research. Use of the remote sensing Landsat Thematic Mapper found 162,100 ha of total vegetated area, including forest, in 2000 and 152,000 ha in 2004.1 In comparison EAD (2006) estimated it to be 376,000 ha. While remote sensing has several advantages and used by EAD, the biggest problem identified in the image analysis was the mapping of scattered Acacia trees against background noise – accuracy was in the range 50-64 percent. This was partly a problem of the modest resolution (60 m pixels) and could be improved upon using more up-to-date US, French or Russian satellite imagery whose resolution is over ten times better.

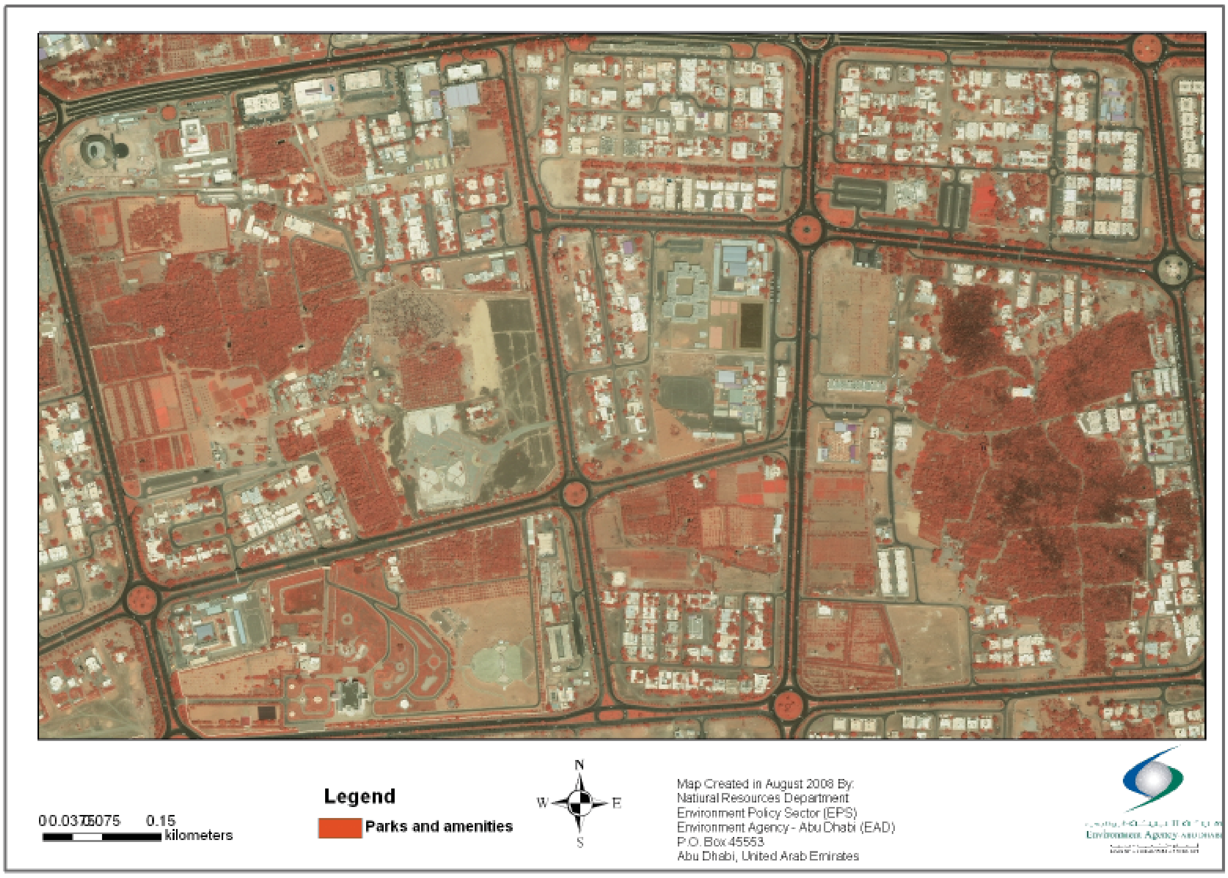


Figure 56: Mapping of amenities and farms in part of Al Ain City (2006).

Improving knowledge on the coverage, health and density of the Emirate's forests is essential. It would reveal their ecological advantages and allow assessment of their development effectiveness against their design objectives: providing protected areas for wildlife sanctuaries; protecting roads from sand incursions, anchoring dune areas; and demarcating UAE's international border with Saudi Arabia. Only thus can the cost-effectiveness of desert greening be evaluated.

6.1.5 Industrial / Commercial Sector

Detailed information on the source and use of water for this sector is not readily available and is poorly documented. The sector is currently estimated to use only 1.5% of the total water consumed in the Emirate, but this proportion will increase as expansion in the industrial sector is brought about by the development of a number of new industrial estates in Abu Dhabi, Al Ain and elsewhere.

Industrial demands in the western region are small and restricted mostly to the 17 group companies that comprise the Abu Dhabi National Oil Company (ADNOC) whose industrial practices are located both on and off-shore. All of their new projects are scrutinized for mimimum water consumption via an HSE impact assessment process (ADNOC, 2004). Off-shore facilities for the oil and gas sector are located on several small islands and installation platforms with independent desalination water supplies. By far the largest demands are located on-shore, mostly at the self contained industrial complex at Ruwais which was inaugurated in 1982 with the commissioning of the ADNOC oil refinery. The Ruwais industrial and housing zone was established to develop industries and processing plants at the downstream side of the oil and gas industry. The complex, which is part of the industrial development plan of Abu Dhabi, overseen by the Industrial Areas Supervision Committee, comprises the following facilities:

- Oil Refinery (TAKREER).
- Natural gas liquids fractionation plant (GASCO).
- Fertilizer Plant (FERTIL).
- Petro-chemical (polyethylene) plant.
- Marine terminal.
- Sulphur handling terminal.
- Un-leaded gasoline plant.

A large housing complex at Al Ruwais comprises more than 1300 units and houses about 20% of the total population which inhabits the western region. The housing complex consumes 1.4 Million m^3/yr of water (57% Treated Effluent, 43% potable). Table (26) provides a summary of the water consumption and water sources for the various ADNOC group companies. Water sources for the various industrial users comprise desalinated sea and groundwater, untreated groundwater, raw sea-water and treated effluent. Produced water includes formation water brought to surface with oil & gas exploration activities and also brine reject water from desalination processes. For the western region, ADNOC group industries consume a total of 1.3 billion m^3/yr of water from the above sources according to 2007 statistics; raw sea-water constitutes 92% of the total, produced water 5.5%, desalinated water 2.4% and the remainder from shallow groundwater and treated effluent.

Most of the total water used is for cooling and utilises seawater. Potable water amounts to 2 % of the total. Oil produced water is generally treated in order to reduce the oil in water content before it is injected into deep wells which penetrate the carbonate Umm er Radhuma Aquifer. Table (27) provides details of oil produced water which is re-injected back into deep aquifers by the ADCO operations. By 2003, all onshore (ADCO) and offshore (ADMA-OPCO) produced water (325,000 m^3/d) was re-injected into deep reservoirs, including water required for reservoir pressure maintenance.

ADNOC's objective is to re-inject produced waters and other effluents, unless their discharge quality is compatible with the surface environment and can therefore be discharges in line with international standards (ADNOC, 2004). All harmful process effluents (12,300 m^3/d) are re-injected into deep disposal wells. At present, no down-hole oil-water separation takes place in the oil recovery process. By leaving the oil polluted waters in the host oil reservoirs, the potential for pollution of other aquifers is eliminated and the need for re-injection into other useable aquifers disappears. Technology for oil-water separation at source does exist and is being tested in other GCC states (e.g. Oman). ADNOC should be encouraged to follow the same path since the amount of oil produced water, although small in relation to that found in Oman for example, is still significant in terms of its contribution to polluting other aquifers, e.g. Umm er Radhuma.

In the Al Ain area, only two industries have been identified which have an independent water supply from pumped boreholes linked where appropriate, to desalination units on site; these are the Al Ain Mineral Water Company and the Coca Cola bottling plant. Apart from these exceptional arrangements, it follows that all industrial demand is being met from bulk water supplied by the distribution companies AADC and ADDC through their networks, and therefore industrial demand is given by the bulk supply figures.

In the commercial sector, the largest users of water are the various bottled water companies, the development of which has mushroomed over the last 5 years or so. Whilst the actual amounts of water used are small, the economic value of the bottled water is high and the products are in high demand.

Table 26: Summary of ADNOC group company annual water consumption for 2006 (m^3/day).

COMPANY / ENTITY	Desalinated		Treated Effluent	Seawater	Shallow Groundwater	(oil produced water etc)	Total
	Industry	potable					
Ruwais Housing Complex	614,657	not specified	816,608				1,431,265
Ruwais Fertilizer Industries (FERTIL)	7,650	929,950		223,273,000			224,210,600
Abu Dhabi Marine Operating Co.(ADMA OPCO)	768,370					57,443,809	58,212,179
Abu Dhabi Oil Refining Co. (TAKREER)		2		505,452,000			505,452,002
ADNOC DISTRIBUTION	100						100
Abu Dhabi Gas Industries Ltd (GASCO)	823,440	795,700	344,560	219,000,000			220,963,700
ESNAAD	255,234	25,943					281,177
TOTAL ABK		22,400,000		5,332,000		5,716,000	33,448,000
ZAKUM Dvelopment Co.	237,300					3,000,000	3,237,300
Abu Dhabi Polymers Co Ltd (Borouge)	875,490	461,658		267,296,858		353,300	268,987,306
Abu Dhabi Co. for Onshore Oil Operations (ADCO)		4,440,522			3,204,262	3,605,382	11,250,166
Bunduq Company Ltd		70,000		4,833,403		1,392,577	6,295,980
TOTAL	**3,582,241**	**29,123,775**	**1,161,168**	**1,225,187,261**	**3,204,262**	**71,511,068**	**1,333,769,775**

Table 27: ADCO production for water re-injection (m³/d).

Oil Field	2002 re-injection	2003 re-injection
Asab	5100	6370
Bab	2400	2400
Buhasa	7000	3185
Sahil	160	320
Shah	160	320
TOTAL (Mm³/yr)	5.41	4.6

6.2 Future Water Demand

6.2.1 Population and demographic changes over years

Population in the Abu Dhabi emirate, inclusive of Al Ain, the Western region and the Islands, stood at 1,463,491 as of end 2006, comprising one third of UAE's total population. Population grew by a compounded average of 4 % annually between 2001 and 2006, and a similar growth is expected until 2010, when the emirate's population is forecasted to reach over 1.75 million. Presently urban residents comprise abi's total population and annual growth in the number of urban dwellers from 2001 and 2006—at 4.93%—has been slightly higher than the emirate's average.

In addition to the locals, the population figures include many expatriate residents who live and work in the emirate. Across the UAE, Emirati nationals comprise roughly 20% of total population, while expatriate workers' nationalities include Asians, Africans, Europeans, as well as from both North and Latin Americas. The projected population till 2030 for the Emirate under different population growth rates is given in Table (28).

Table 28: Population growth and projected population, Abu Dhabi Emirate

Year	Population	Per capita water consumption (m3)	
2005	1292119	0.35	
Growth rate and projected population			
	Low (3.7%)	Medium (5.8%)	High (7.9%)
2010	1594230	1618994	1751412
2015	1791890	2146216	2561507
2020	2148845	2845128	3746302
2025	2576908	3771640	5479109
2030	3090243	4999868	8013407

6.2.2 Economic development strategies and plans of Abu Dhabi Emirates

Economic development is the priority policy area of the Government of the Emirate of Abu Dhabi. Key elements of the Emirate's vision describe a dynamic open economy, characterized by a vibrant diversity and by transparency and sound governance.In 2006 the Emirate of Abu Dhabi commenced an historic Government restructuring program with the aim of boosting efficiency and enhancing Government productivity to ensure improvement in how the Government serves the needs of its people and visitors. In order to ensure Government is an enabler of economic growth rather than a barrier to it, all Government processes were reviewed. The purpose of the review was to make Government more responsive to the needs of a growing population, and more able to sustain and prolong economic growth. The desired outcome is a new structure based on the government as a regulator rather than an operator of services.

With the restructure, the Government intends to broaden the base of the economy and promote the role of the private sector as a provider of services for residents and visitors. The essence of the restructure is for Government to become the regulator of services delivered to its people, and for the private sector to become the provider of those services. The complete result of the Government restructure will not be fully realized until 2009, but more than half of the planned restructure of Government is already complete, and the benefits of the reform are quickly becoming apparent.

The rapid social and economic growth experienced by Abu Dhabi in recent decades has additionally stimulated unprecedented demand on the institutions of Government in the Emirate. This demand, combined with complex reporting frameworks and overlapping responsibilities created a situation in which more than 70 separate entities were reporting directly to the Executive Council. In addition, 71 percent of the 1,258 decisions made by the Executive Council in the year before restructuring commenced were transactional, rather than strategic in nature. This transactional focus of the Executive Council was hindering its ability to perform its primary strategic functions. However, efforts are made to implement programs on several sectors such as water which is one of the important components of the Government programs.

Conventional water resources do not meet the national demand for fresh water and the desalination of sea water is now the main source of drinking water in the Emirate (MEW, 2004). There have been sharp increases in demand and consumption per capita. Several estimates have been discussed regarding the future demand. For example, the consumption per capita in 1997 was 130 gallons/day and this value increased to 199 gallons/day in 2002. The annual net water production for the year increased by 8.7% to 177,500 MG. Water demand in Abu Dhabi Emirate thus is expected to increase in the next ten years from around 208 million gallons per day in 2000 to about 700 million gallons per day in 2010 and 800 million gallons per day in 2015 (ADWEC, 2003). Keeping these estimates as well as other details, future projections are made with the following assumptions:

Population:

- Population growth is 3.7% per annum (current level).
- Population growth is 5.8 % per annum (medium growth level)
- Population growth is 7.9 % per annum (high growth level)

Water Supply:

Groundwater (domestic wells) supply will decrease by 5 % from 2010 to 2015; 7% from 2016-30. Waste water supply will be 90% of the domestic water used. Out of the total wastewater produced (eastern region = 31.52 mm3/yr and western region = 118.37mm3/yr), 8% and 15% will be lost to sea and unaccounted for in the two regions respectively.

Water Demand:

Agriculture water demand will be increasing 2% per year till 2030. Residential demand is worked out multiplying the projected population by the per capita water use (0.35 m3). Non-residential demand is worked out by deducting the residential demand from the total domestic use in the base year and then projected with a growth rate of 2% per year.

Growth in irrigation demand in forestry sector will be 1% up to 2015 and then 2 % Growth in irrigation demand in amenity sector will be 2% per annum Industry demand will increase by 2% per annum. The projected water supply and demand were arrived for the following scenarios as shown in Table (29).

Table 29: Projection Scenarios for water supply and demand for Abu Dhabi Emirate.

Scenario	Assumptions
Business as usual:	
1.	Business as usual (BAU) (current population growth of 3.7% per annum) and other things will continue as such without any change
Growth in Population and Agriculture sector:	
2.	Business as usual with medium population growth (5.8%/year)
3.	Business as usual with high population growth (7.9%/year)
4.	Business as usual with agricultural demand grow at 2.0 %/year
Supply side interventions:	
5.	Supply side interventions (incorporating the full utilization of the treated waste water supply) with BAU scenario
6.	Supply side interventions (incorporating the full utilization of the treated waste water supply) with medium population growth (5.8%)
7.	Supply side interventions (incorporating the full utilization of the treated waste water supply) with medium population growth (7.9%)
8.	Supply side interventions (incorporating the full utilization of the treated waste water supply) with agricultural growth (2.0%)
Demand side interventions:	
9.	Demand side interventions incorporating: (i). Reduction in per capita domestic consumption by 10%, (ii). Allocation of treated waste water in agriculture sector by 5% in 2015 to 2020 and 10% in 2025 and 20% in 2030 with low, medium and high population growth & 2% agricultural growth iii). Allocation of treated waste water in forestry sector by 5% in 2010 and 10 % in 2015 and then 20% in the remaining years with low, medium and high population growth & 2% agricultural growth
Supply and demand interventions combined:	
10	Combinations of scenarios 5,6,7,8 & 9

6.2.3 Future Demand in Domestic Sector

Domestic water demand includes mainly residential, commercial establishments, hospitals, hotels, offices, and shops. The significant increase in customer demand for water occurred mainly in government sponsored housing development schemes and agricultural activities; particularly in the farming and forestry sectors. In 2005, 23 % (719 Mm^3) of all water consumed in Abu Dhabi Emirate was in the domestic sector; 98% from desalination, 2% only from groundwater wellfields. All of the 16 producing wellfields, containing 600 wells, of which 333 only are operated, are located in the Eastern Region; wellfields in the Liwa area of the Western Region have been discontinued for domestic supply due to water quality difficulties.

Previously, all of Al Ain City's domestic water requirements were met from wellfields, however, massive increases in domestic demands has meant that wellfields have been placed under increasing stress, resulting in declining water levels, increase in groundwater salinity with a resultant decrease in total production. Thus the environmental impact of the declining water table is a growing concern now.

Total domestic wellfield production had reduced to only 12.3 Mm³/yr, meeting only 1.7% of the total domestic requirements in the Eastern Region. Since 1998, production from the domestic wellfields has decreased by over 60%. Despite their costly operation for a relatively small to moderate production, the wellfields continue to operate since they are strategically important as an emergency back up to any potential failure in the supply of imported desalinated water to the Eastern Region. The balance of domestic demand in the Eastern Region and also the full requirements for the Western Region, are now met by desalinated water. The new Shuweihat plant, under construction in the Western Region, has the largest Multi Stage Flash (MSF) units in the world, each capable of 80,000 m³/d.

Future potable water supply demand in Abu Dhabi is currently based on forecasts by ADWEC (2007), but what is becoming increasingly clear is that the probable accelerating rate of planned development in Abu Dhabi between the present and 2030 and its impact are, only very recently, becoming incorporated in the forecasts developed by ADWEC as shown in Table (30). Figure (57) shows the Abu Dhabi water peak base demand forecast up 2020 per each regional area. The most predicted increase in demand will be in Abu Dhabi and the less will be in western region.

ADWEC forecasting indicates that the deficit will be about 475 MGD in 2030. This means that a lot of investment is required to increase the supply capacity as well as reduce the demand through demand management strategy. Hence necessary awareness programs should be prepared in such a way that people will understand the value of water in alternative uses as well as cost of producing the water.

Table 30: Forecast of Water Capacities and Demand MGD (2006 – 2020)

Year	Available Capacity	Demand	Required Capacity	Surplus / Deficit
2006	620	553	581	67
2007	620	580	612	8
2008	664	592	626	38
2009	660	620	651	9
2010	786	742	779	7
2011	835	815	856	-21
2012	834	848	892	-58
2013	833	877	927	-94
2014	832	905	949	-117
2015	831	934	978	-147
2016	830	960	1,007	-177
2017	830	987	1,030	-200
2018	827	1,013	1,066	-239
2019	826	1,039	1,090	-264
2020	825	1,065	1,113	-288
2021	830	1091	1136	-261
2022	850	1117	1159	-267
2023	850	1143	1182	-293
2024	850	1169	1205	-319
2025	850	1195	1228	-345
2026	850	1221	1251	-371
2027	850	1247	1274	-397
2028	850	1273	1297	-423
2029	850	1299	1320	-449
2030	850	1325	1343	-475

Notes:

Capacity is shown at the time of system peak, not at the end of the year.

For the years 2007 - 2010 network constrained water supply has been used in place of demand.

The demand forecast years shown in grey are when water transmission constraints are expected to constrain water supply to be less than water demand.

6.2.4 Agriculture Sector

This sector consumes about 58% (1741 Mm³/yr) of all of Abu Dhabi Emirates demands (2006). There were more than 25,000 citizen's farms, occupying around 80,000 ha and a small number of large, state fodder (government) farms occupying about 17,000 ha. Citizens farms are typically 2-3ha in size and each have at least two drilled wells at opposite corners of the plot. Major crops are Dates and Rhodes grass, with some seasonal plantings of short season annual vegetable crops; a limited area of cereals and fruits. A well supported system of subsidies

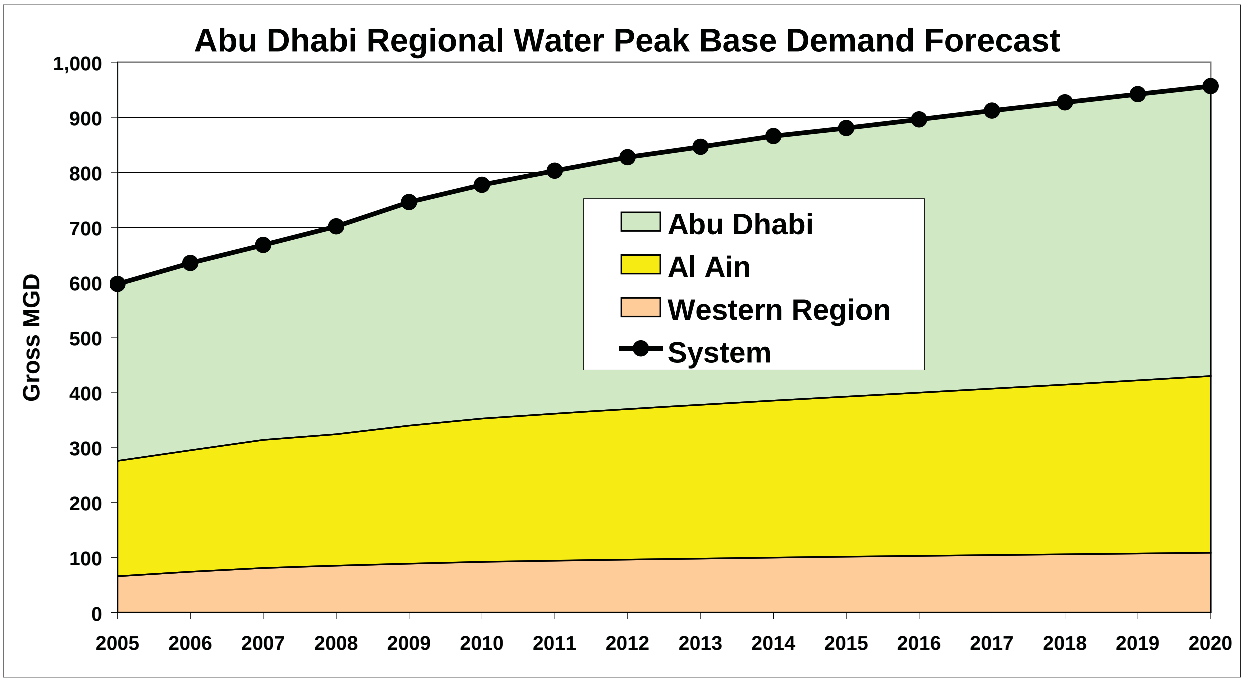


Figure 57: Abu Dhabi Regional water Peak base Demand Forecast.

promotes agricultural expansion to the tune of 3,000 new farms each year, although expansion is currently restricted due to exhaustion of groundwater supplies. The type of crops grown are based on recommendations provided to the farmers from the agriculture extension services departments belonging to the Municipality and Agriculture sections in the Western and Eastern Regions of the Emirate. The major limitations on agricultural development are lack of groundwater resources and high groundwater salinity. The projected forestry demand with shares among the sources and the projected domestic demand are given the Table (31).

Table 31: Projections of agricultural water demand

Agricultural demand in Mm3 (increase 2% / year)					
Base	1732				
2010	1912.27				
2015	2111.3				
2020	2331.04				
2025	2573.66				
2030	2841.53				
Share by different sources in different years					
Sources	**2010**	**2015**	**2020**	**2025**	**2030**
Wells-east	0.56	0.535	0.54	0.51	0.46
Wells-west	0.44	0.415	0.42	0.39	0.34
Desalination-east	0				
Desalination-west	0				
TSW-east	0	0.025	0.03	0.05	0.1
TSW-west	0	0.025	0.03	0.05	0.1

6.2.5 Forestry Sector

This sector protects roads from sand incursions, especially in areas of high dunes, sand dune stabilization in areas of existing developments, providing protected areas for wildlife sanctuary. This sector consumes 11.6% (363 Mm^3/yr) of all of Abu Dhabi Emirates demands. There were around 250 separate forestry plantations, under the management of the Al Ain Forestry Department and the Abu Dhabi Municipality Forestry section. Total area under cultivation is now 305243 hectares, representing an expansion of 26% per annum. Individual plantation sizes range from 4 to 70,000 hectares and 80% of development is located in the Western region. A total of 64 million trees are irrigated by 5,713 wells. In the Eastern Region, 12264320 trees, occupying 56854 ha, are irrigated with 122.85 Mm^3/yr. In the Western Region, 51317276 trees, occupying 243494 ha, are irrigated with 484.45 Mm^3/yr (EAD, 2006).

This sector is faced with operational challenges related to poor water quality, lack of sufficient quantity of irrigated water and also poor quality soils. Both groundwater quality and well yields are reported to be slowly deteriorating and increased use of desalinated water is foreseen. In order to optimize tree growth potential under these difficult conditions, emphasis has been placed on growing indigenous species, such as Prosopis cineraria (ghaf), Salvadora persica (tooth brush tree), etc In the Eastern Region, these two species alone account for over 60% of all trees. The projected forestry demand with shares among the sources and the projected domestic demand are given in Table (32).

Table 32: Projections of Forestry water demand

Forest demand in Mm3 (increase 1% for 2010 & 2015 and 2% afterwards)						
Base	362.38					
2010	380.865					
2015	400.293					
2020	487.716					
2025	538.478					
2030	594.523					
Sources	**Share by sources in different years**					
Forestry well fields	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Eastern region	0.345	0.32	0.295	0.245	0.245	0.245
Western region	0.655	0.63	0.605	0.555	0.555	0.555
Desalination-east	0					
Desalination-west	0					
TSW-east	0	0.025	0.05	0.1	0.1	0.1
TSW-west	0	0.025	0.05	0.1	0.1	0.1

6.2.6 Effluent generation

Also the waste water production from the domestic (residential) sector water use will be about 90 % or 0.3 m3/c/d (ADSSC, 2007) and the waste water production of about 150 Mm3 in 2005 also confirms this. Hence the details of the non-residential use should be re-examined in detail. Also the EAD report, 2006, had indicated that about 35% of the desalinated water is unutilized, which also signals that actual use of the non-residential water may even be lesser than what we could imagine. Hence, in the following projections, the quantum of residential water so derived is used to arrive at the waste water generated. Table (33) shows the projected effluent generated with low, medium and high population growth up to 2030.

Table 33: Projected effluent generated with low, medium and high population growth.

Year	Effluent generated (Mm3/year)		
	Low	Medium	High
2010	171.80	186.14	201.37
2015	206.02	246.76	294.51
2020	247.06	327.12	430.73
2025	296.28	433.64	629.96
2030	355.30	574.86	921.34

7 Major Water Challenges

7.1 Present Challenges

The lack of the renewable freshwater resources in Abu Dhabi Emirate constitutes a major deterrent to its sustainable development. On the other hand, growing population, rising standard of living, and expanding opportunities exert increasing demands for varied needs for freshwater in the Emirate. These needs may be domestic, agricultural and forestry, industrial including oil and gas extraction, waste disposal, power generation, recreational, and so on. To meet demands for water for a multitude of such needs is a continuing struggle. Proper planning and management of the limited available water resources in the Abu Dhabi Emirate is essential to maintain the current development and economic boom in the various sectors of the Emirate. The Emirate is, therefore, faced with enormous challenges to provide potable water for various needs.

Due to the tremendous increase in the living standards in the Emirates over the last 2-3 decades the per capita consumption of freshwater has reached very high levels which by far exceed the average rates. Meanwhile, the per capita share of renewable freshwater (not including the desalinated water) in the Emirate has dropped significantly due to burgeoning population and the attendant increasing need for water. Notwithstanding these severe shortages, water continues to be used unwisely, wasted and polluted. Insufficient water at the right place at the right time with the right quality requires, more than ever before, improved management, efficient utilization, and increased conservation of limited freshwater resources in the Emirate. These demands can only be met if water resources are conserved, planned and properly managed.

The main reasons for the water shortage problem in Abu Dhabi Emirate are related, in someway or the other, to the following:

- Rapid increase in water demands in the various water consumption sectors to cope with the booming economy and industrial development in Abu Dhabi Emirate. The per capita share of freshwater consumption has tripled during the last three decades.
- The average annual precipitation over UAE and the Abu Dhabi Emirate has reached its lowest levels during the last 10 years. This might be associated with the global warming phenomenon. As a result, the natural recharge of groundwater systems in the Emirate was negligible.
- Deterioration of groundwater both quantitatively and

qualitatively due to the excessive pumping mainly for agriculture purposes along with the extensive use of chemicals and fertilizers in agriculture.

- Slow transfer of technologies from applied research to practice, due to poor coordination and poor networking among stakeholders. The gap between the developments in sciences related to water conservation techniques and application of the technology is still huge.

- Absence of integrated water resources management approach and practices. Long-term strategies for water planning, management and conservation are not in place.

- Low water use efficiency and high water losses in the water distribution systems. The leakage from the distribution networks has never been properly assessed. The lack of maintenance and rehabilitation programs to improve and maintain system performance has contributed to the severity of this problem.

- Shortage of available funds for water development and conservation projects. Water projects are usually massive and require high investments. On the other hand, economic returns of water development and conservation projects are generally low as compared to other investment sectors.

- Difficulties in changing the unfavorable social habits and attitudes towards water uses and conservation. This is mainly due to poor public awareness programs in the Emirate. The education curriculum at primary and elementary schools do no address water conservation in a proper manner.

The following major water management issues have been identified as part of ongoing EAD studies in developing a water resources management strategy and action plan for the Emirate of Abu Dhabi:

Water use: policy, planning and regulation

- Reduction in quantity and quality of groundwater through over-abstraction, resulting in Stalinization of land, reduction in crop yields and abandonment of farms.

- Lack of farm management leading to over- irrigation and drainage problems.

- Unplanned development in the farming & forestry sectors.

- Poor performance of the Forestry Sector due to insufficient water and poor water quality.

- Little or no effort to manage the demands for water in agriculture sector.

- Lack of recognition of the true economic cost of water when assigning its use.

- Uncontrolled and un-regulated well drilling, leading to dry wells and wasted resources.

Protection, conservation and monitoring of water resources

- Lack of official, co-ordinated, Emirate-wide water resources monitoring network and programme.

- Groundwater pollution due to fertilizer use.

- Lack of groundwater protection policies, e.g. no protection zones for municipal wellfields that still produce drinking water.

- Incomplete records, little on-site monitoring or measurement of water resources, especially whilst drilling new wells, and lack of inventories on sources and demands.

- Lack of qualified, technical, on-site supervision, monitoring and data collection during drilling and general water resources monitoring.

- General waste of water and leakages.

Water data and information management

- Non-availability or poor access to water resources information and data, and lack of a central, Emirate-wide database to hold and analyse water resources data and information.

- No well inventory, poor data collection when drilling wells.

- Environmental Impacts of Desalination Plants are not sufficiently assessed (Brook & Dawoud, 2005).

Coordination of groundwater exploration and assessment

- Need for expansion of groundwater exploration programmes, especially for deeper aquifer potential (although chances of finding new reserves of fresh water are very slim)

- Lack of coordination and collaboration between existing groundwater exploration and assessment programmes

Local, regional & International cooperation and collaboration

- Little or no technical cooperation with neighbouring countries, especially on developments on or near to the international boundaries

Strategic emergency water resources

- No developed strategic reserve of potable quality water in case of emergency (current reserve is less than 2 days of water demand)

Common to the solution of most of the issues and problems listed above is the requirement for the establishment of a central, independent authority for Water Management in Abu Dhabi Emirate.

This fragmented arrangement is unsatisfactory for effective water management and results in lack of coordination and collaboration between some of the bodies, duplication of efforts, non-assignment of responsibility for some very important aspects of water management, wasted funds and a general lack of accountability for some organizations current practices which go against the principle of sustainable water resources management and rationalization of water use.

Abu Dhabi is one of the most rapidly developing arid regions in the world, especially with respect to urbanization. The effects of urbanization on groundwater systems have continued to draw increased attention. The construction of buildings, roads, and sewer lines greatly affect many factors of the water cycle, however, there have been no studies conducted to evaluate the effect of rapid urbanization development on water resources, in terms of quantity and quality. The produced wastewater is treated and fully utilized in the Emirate. It is used in amenity plantations, road verges and parks using dripping or sprinkler irrigation system. Leakages from the sewer systems are un-quantified, but would most certainly pose a risk of pollution to groundwater resources.

The expansion in the agriculture sector over the last 20 years or so has been immense, as part of an overall greening policy. Groundwater pollution from agriculture activities could be from extensive use of fertilizers, pesticides and/or form the agriculture landfills.

Essential plant nutrients occur naturally in soil. To increase crop yield, growers supplement soil nutrients by adding chemical fertilizers and organic fertilizers such as animal manures and crop residues. Because excess nutrients can move below the root zone, managing plant nutrients is an important part of protecting groundwater quality. The soil in Abu Dhabi Emirate is poor and loose sandy soils and therefore it is essential to add organic materials and chemical fertilizers to improve the soil and increase the productivity. The high permeability of the loose sandy soil increases the seepage and also the nitrate leaching to the aquifer system. In 2005 (FEA/ERWDA, 2005), 228 samples were collected from farm production wells in Abu Dhabi Emirate and 30 % of the samples exceeded the WHO maximum allowable Nitrate levels for drinking water. Figure (58) shows a summary of Nitrate levels in groundwater. Nitrate is of particular concern because it leaches easily and poses health risks for infants and adults alike.

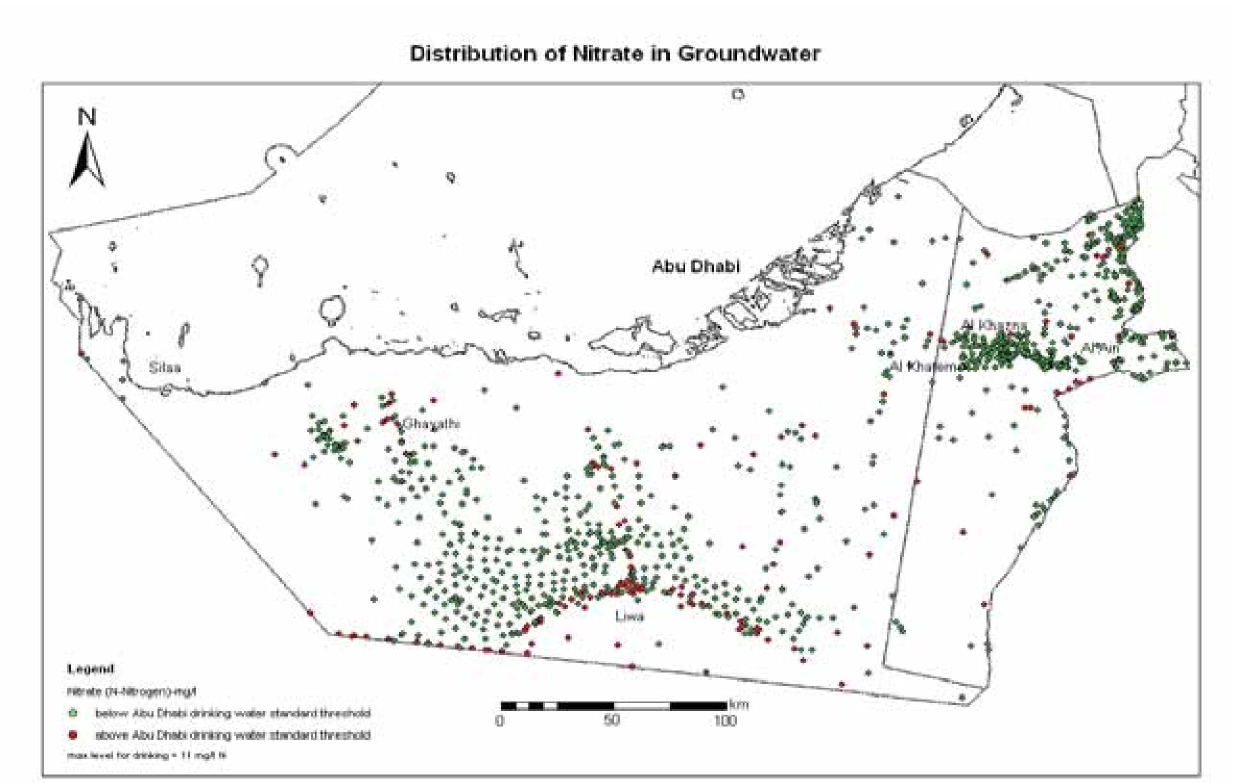


Figure 58: Distribution of nitrate in groundwater in Abu Dhabi Emirate.

About 406 deferent types of pesticides are used in agriculture in the UAE, as shown in Table (34) (MAF, 2004). An analysis of historical information indicated an increase in the use of pesticides between 1996 and 1999 and a decrease after 2000. This could be due to the change in agriculture policy by increasing the areas cultivated with Rhodes grass and decreasing the areas cultivated with fruits and vegetables. In a joint FEA/EAD study in 2005, over 200 groundwater samples were collected from Abu Dhabi Emirate for pesticide analysis (ERWDA/FEA, 2005). 30 compounds of chlorinated pesticides were analyzed but only one sample contained a (low) concentration of pesticide residues. Also, the results reported by the Agriculture Department in Al Ain for samples collected from Eastern Region of Abu Dhabi Emirate indicated that there are no pesticide residues in groundwater (Al Ain Municipality & Agriculture, 2004c). This could be due to the following reasons:

1. Using drip and sprinkler irrigation system which not allow for high seepage.
2. The high temperature which could affect the vitalization rate of the pesticide.
3. The groundwater in many areas is deep.
4. The adsorption effect of unsaturated soil.

Agriculture landfills contain a wide variety of wastes such as unsuitable vegetables, construction materials, plastics, dead animals, and household garbage. After damping, the refuse is burned and then sprayed with water to prevent wind transport of flashes. The potential groundwater contamination from these landfills has been studied by the NDC/USGS project (NDC/USGS, 2005). Groundwater samples were collected and analyzed from a location near Al Hayer. It was shown that Dissolved Organic Carbon (DOC) concentrations in some wells were low.

Table 34: List of pesticides used in farming in the UAE (MAF, 2004)

No.	Classification	Number	Use
1	Insecticides	83	Allowed
2	Soil Insecticides/Nematocides	13	Allowed
3	Acaricides	4	Allowed
4	Fungicides	61	Allowed
5	Natural and Bio-Pesticides	24	Allowed
6	Insect Growth Regulators	9	Allowed
7	Herbicides (Restricted)	18	Restricted
8	Chemosterilizers (Restricted)	6	Restricted
9	Pheromones	14	Allowed
10	Deodorizers	5	Allowed
11	Adjuvants	6	Allowed
12	Restricted pesticides	34	Restricted
13	Miscellaneous	6	Allowed
14	Public health (General)	87	Allowed
15	Public Health (Restricted)	31	Restricted
16	Public Health (Miscellaneous)	5	Allowed
	TOTAL	**406**	

If contaminants from the landfills were reaching the water filled sand and gravels, elevated concentrations of DOC would be expected. The absence of elevated concentrations of DOC indicates that the landfills are not contaminating groundwater. However the landfills still may be a risk to the underlying aquifer because the landfills are not lined and are underlain by very permeable sandy soil, which floods periodically. These factors might provide a mechanism for contaminants migration downward into the aquifer with time.

7.2 Facing the Challenges

7.2.1 Management of data and information on water

Currently, there is no single, central water information network, encompassing all water sources and users within the Emirate. EAD developed a simple database for the eastern region only in 2004 (ERWDA/MMI, 2004i, Dawoud et al, 2005) which included all aspects of water sources and users, but this now needs to be expanded.

It is foreseen that the following databases will continue to be managed by the respective agencies as shown:

Groundwater EAD

Domestic /Bulk water Supply
ADWEA

Treated Wastewater (western region)
Sewage Projects Committee

Treated Wastewater (eastern region)
Al Ain Municipality & Agriculture

For groundwater, EAD has recently called for proposals to establish a centralised GIS database which will be capable of storing, analyzing and producing graphical output and statistics on the following aspects:

- Exploration
- Monitoring
- Water Use
- Water Supply
- Well Permitting
- Well Registration
- Company registration
- Assessment
- Modeling
- Meteorology
- Mapping

The water information obtained was eventually being accessible online as part of EAD's current commitment to achieving e-service government status at the end of 2006.

It is foreseen that ADWEA will continue to update and manage its GIS assets database for all of its structures and utilities. The wastewater GIS programme is currently managed by Abu Dhabi Municipality and Agriculture, through Hyder Consutants, UK. It would be beneficial if a similar, compatible GIS database could be also developed for the eastern region and that data exchange would take place on a regular basis between the two.

7.2.2 Groundwater Monitoring Systems

With the advent of assigning the responsibility of groundwater management to EAD, there is now a golden opportunity for developing a national groundwater monitoring network for the first time. In 2005 a national groundwater monitoring system which was installed through the GWA program was handed over to EAD.

There are three main components of a successful Groundwater Resources Management Strategy, namely:

- A comprehensive water information (database) network
- Developed and enforced groundwater regulations
- A nationwide monitoring system.

All three components are closely linked and complement each other. None of the above three components currently exist for the Emirate of Abu Dhabi. A comprehensive groundwater monitoring network, for groundwater levels and groundwater salinity, is required throughout the entire Emirate in order to provide the baseline data for assessment of the general water situation found of the two regions. Continuous groundwater monitoring, either remote or manual, provides the necessary data for the assessment of trends and forms a basis for general water management and development options in the various regions. Data should be stored in a national water information network which would be supported largely by the development of a GIS water resources database. The existing EAD GIS database is currently being adapted to meet the requirements of such a national water information network (Brook, 2005b).

A sound and efficient monitoring system allows for the regular reporting of the water situation in the various regions of the Emirate and provides the basis for decision making in terms of overall groundwater development and regulation. A part of a region which has experienced severe groundwater declines and deterioration of quality should not be proposed for additional development. The results of the water situation reporting should be conveyed to those responsible for well permitting. On the contrary, an area where groundwater levels and water quality are stable, and providing for a sufficient aquifer storage for sustainable development, could be considered as providing potential for new development activities.

It is essential that the results of monitoring should be made transparent and that the information be provided on a regular basis to water users throughout the Emirate. This will be achieved by issuing regular groundwater resources monitoring reports.

Groundwater monitoring and associated sampling must have a clear objective and the function of the monitoring points must be identified during the design of the system, not least because implementation of a monitoring system is necessarily a long term project and will require expensive resources. Sampling and measurement must be carefully designed; sampling technique, measurement frequency and measurement error must all be considered and must be appropriate to the objective and to available resources.

The required monitoring systems will be based upon measurement of various water resource parameters which could include:

- Static (un-pumped) or dynamic (production) water levels in production wells.
- Water levels in un-pumped observation or monitoring wells.
- Well or wellfield (sampled reservoirs) output and salinity.
- Water chemistry through salinity-conductivity measurements or the measurement of specific chemical species. Chemistry is a potential indicator, for example, of the ingress of saline water into an aquifer (through seawater intrusion or the up-coning of deep saline groundwater) or the presence of polluting species (for example nitrates or pesticides derived from agricultural activity). Unstable species (such as pH, dissolved gases) may be monitored as indicators of corrosion-encrustation potential of the groundwater.
- Biochemical e.g. coliforms etc.

As previously stated, there is currently no central groundwater monitoring system for Abu Dhabi Emirate. Monitoring, however, is carried out by various projects and other government agencies who are largely the main users of groundwater, as follows:

The USGS-NDC groundwater research program (USGS 1996), established in 1988, considers groundwater monitoring as an essential part of their mission. In addition to weather data monitoring, up to 1800 boreholes are monitored, as shown in Table (35).

Table 35: Summary of USGS/NDC Program monitoring network

Number of Boreholes Monitored	Parameter	Frequency
53-70	Static water level (SWL)	Monthly
400	Static water level (SWL)	Annually
1800	Water Quality; full chemical analysis for all wells drilled by USGS (>400)	Once/ intermittent [but regular measurements to be started]

In addition, some monitoring is carried out at specific sites (perhaps as part of a hydrogeological investigation) and in areas where resources are developed by other agencies, e.g. Al Ain Forestry Department; such activities include:

- Observation wells/piezometers set outside the boundary of afforested blocks, to detect water level impacts of pumping;
- Jabal Hafit boreholes;
- As part of a project to study nitrate build up as a result of the application of fertilizers on farms, observation wells/piezometers near to agricultural areas, and in areas where no agricultural development has yet taken place, are monitored for water level & water quality changes.

The USGS -NDC program has a current objective of creating a water quality monitoring network, to indicate chemical trends with time. All of the monitoring data is available in a database maintained by the GWRP in Al Ain.

The GTZ/DCO Groundwater Assessment Project (GWAP) constructed a monitoring system to support their project objectives of shallow & deep groundwater resource assessment and the creation of a sustainable water resources management system in Abu Dhabi. The longest well record is 7 years, in the Al Khazna area. The GTZ/DCO monitoring programme, at time of handover to EAD, is shown in Table (36). The GWRP and GWAP combined monitoring network is shown in Figure (59).

There has been little or no cooperation between the GWAPand GWRP groundwater monitoring programmes over the last decade. Sometimes, different project wells are found side by side. The GWRP wells are mostly concentrated in the eastern region and the GWAP wells in the western region.

Table 36: List of GWAP monitoring stations.

		Groundwater Monitoring			Meteorological Monitoring		
		WL	EC	T	Precipitation	Soil Moisture	Meteorology
Continuous Monitoring	Number of wells	285	83	83	23	2	4
	Frequency	single measurement every three hours/day					
Periodical Monitoring	Number of wells	58	58	58	0	0	0
	Frequency	monthly					

Distribution Companies: AADC

AADC operates wellfields for potable water supply in the Al Ain area; 2005 production from about 200 production wells was around 27,000 m^3/d. Production is far less than nominal installed capacity and this is indicative of production problems related to either salinity rises, or to falling water levels in the wellfields giving declining well yields and borehole engineering problems. Some of the original ADDC wellfields are now completely out of production.

AADC has for a long period carried out regular monitoring of operating production wells, for the parameters of conductivity, pump output, static water level and pumped water level. Output is chemically analyzed but only sporadically. In some of their wellfields, AADC have also established monitoring or observation wells (for example, Karaa Wellfield) based upon abandoned production wells. These have since 1999 been fitted with automatic water level monitoring equipment with centralized data collection. However, the signal received from the logging equipment is faulty and, therefore, there are no valid observation data currently available.

The priority of the AADC wellfield operations management is to meet Al Ain demand for potable water which they meet by blending the wellfield water although peak demand is currently not met. The monitoring programme is thus seen as Potable Water Supply Surveillance Monitoring. It is focussed upon the production wells with the principle objective of detecting water level trends which, if uncorrected, would lead to water levels reaching the pump intake zone and pump failures or damage. In this situation, operations staff typically will reduce well output or reduce pump size.

Other Agencies

Within other agencies, it seems that there is very little systematic measurement or monitoring of water resources parameters. The drilling/maintenance Section is responsible for the drilling, development and testing of new farm wells and although the drilling contractor will record static water levels (SWL) in a newly drilled well, operating water levels and output are not subsequently monitored. Water levels are then measured on an adhoc basis and there is no regular monitoring routine.

The success and viability of farms is probably not systematically monitored yet there are reports of farm and borehole failures, some because of excessive groundwater salinity or aquifer exhaustion. This indicates the need for increased farm/aquifer/borehole planning and farm monitoring.

In the western region, agriculture wells are monitored on a similar basis by the Department of Agriculture of Abu Dhabi Municipalities and Agriculture. No systematic monitoring takes place.

The Al Ain Forestry Dept has jurisdiction over about 2,600 wells in forest areas; the majority of these wells pumps to storage tanks which then provide gravity supply to drip irrigation lines. The Dept estimates their total annual water production of about 96 Mm^3/year, an estimate which seems to be based upon number of wells and average operating hours and daily output of those wells. However, since the Department appears to lack the resources to carry out any measurement or monitoring of forest supply wells, these production estimates should be used cautiously. As part of a recent forestry pilot study (W S Atkins, 2005) on issues pertaining to water management, a two month groundwater monitoring program, comprising 3 wells each in four selected forest sites, was initiated, but has subsequently ceased.

ADNOC has drilled around 10,000 water supply wells for their oil exploration camps and for other oil related installations. Usually four wells are drilled per oil well; three are used for rig requirements, especially mud re-circulation, and one for camp use. No measurement of water level or salinity is taken and no subsequent monitoring is conducted.

Finally, EAD is currently monitoring the water level for four observation wells at the Al Wathbah wetland reserve, 40 km outside Abu Dhabi. Three wells are dipped manually; the other has a SEBA MDS logger installed. Also, EAD, in association with MUBADALA, have completed three wells on the artificial storage and recovery project at Shuwaib. Additional monitoring wells will also be drilled in 2006.

The monitoring systems operated by the NDC-USGS, and by GTZ, prior to closure of the project, have been designed with specific monitoring objectives, and are based upon measurements in boreholes and dug wells whose construction and aquifer details well documented. These systems therefore have the potential to form the core of any future water resource monitoring system and this is the recommendation of this report.

The GTZ network should first be reviewed and assessed. The NDC/USGS Groundwater Research Program (ADNOC) should then be approached with a view to joining the monitoring program and filling in gaps of the GTZ network. In addition, all other agencies current monitoring programmes should be reviewed and recommendations provided for any expansions. Again, agreements need to be reached to provide EAD with groundwater monitoring data on a regular basis. Finally, once all current monitoring facilities have been assessed, a programme of drilling new monitoring stations can commence. Data input to the existing EAD water database would be a continuous activity and update and amendments of the database will be required in order to upload and allow analysis of the data. Existing, inventoried, abandoned wells, where well constructions are known, should also be assessed for possible incorporation into a monitoring network, thus saving on drilling costs.

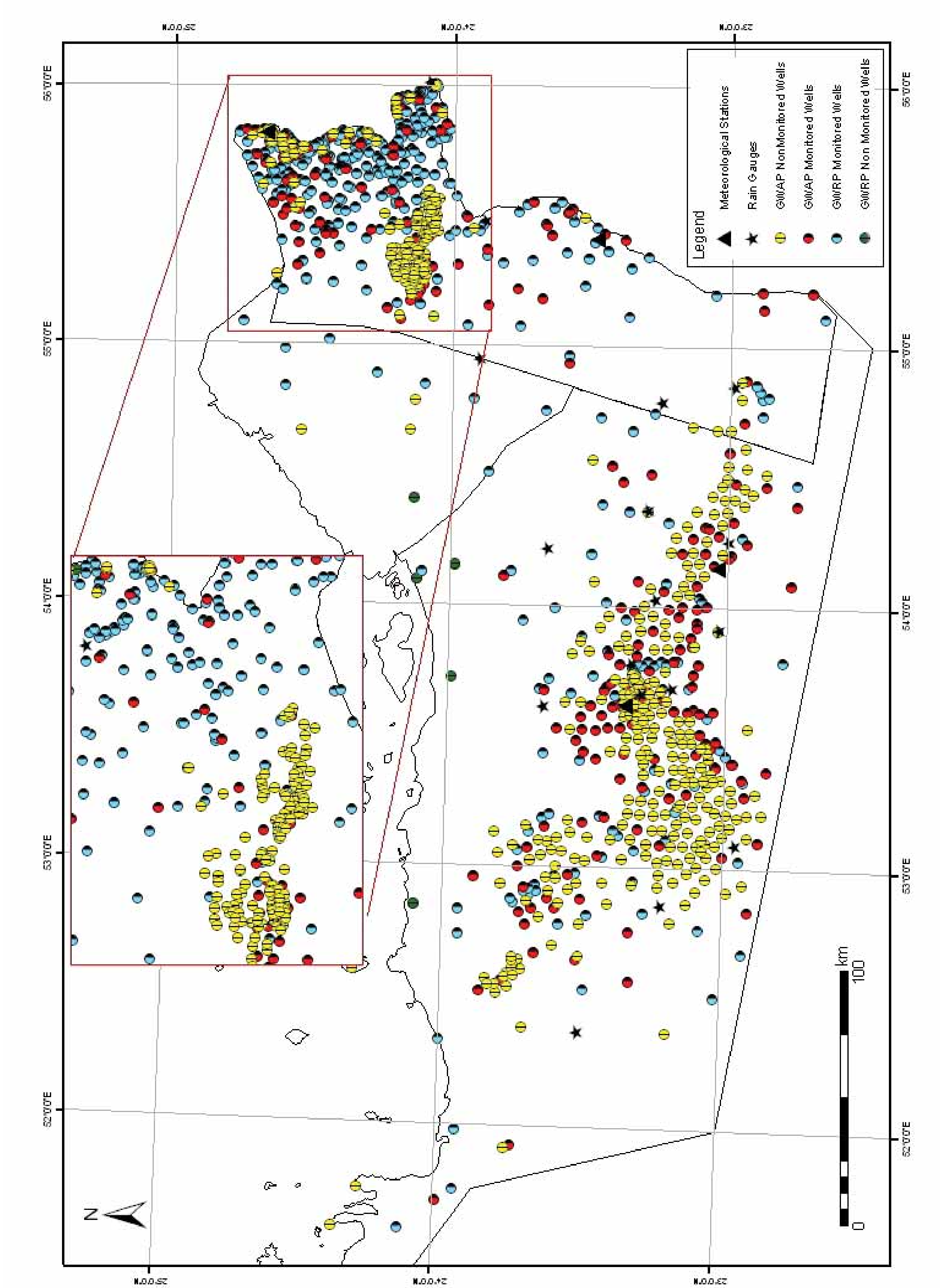


Figure 59: Location of existing groundwater monitoring stations in Abu Dhabi Emirate.

7.2.3 Water Resources Exploration and Assessment

Groundwater Resources Exploration and Assessment has in the past been undertaken largely by GWAP and GWRP groundwater research programs, based in Abu Dhabi and Al Ain respectively.

The former project is now transferred to EAD and the last exploration drilling was completed in early 2005. Over 500 wells were drilled during the last ten years. EAD plans to re-commence a programme of groundwater exploration, albeit limited in scale, by mid-2009. The GWRP has drilled nearly 500 wells for exploratory and monitoring purposes, but the most current wells are dated 2006. This means that no agency is currently conducting groundwater exploration in the Emirate. This situation needs to be rectified as soon as possible,

Whilst it is largely recognized that the potential for discovery of new fresh water reserves is extremely limited, there may be opportunities for deeper exploration which may find useable groundwater reserves. The exploration campaign should also include rehabilitation of existing groundwater monitoring wells and also filling of gaps with new observation wells. Other sites of scientific interest may also be incorporated into the exploration program.

7.2.4 Increase Use of Treated Wastewater

Treated wastewater will be an integral part of water resources in the near future given the rapid expansion of wastewater treatment networks. The treatment level and methods compatible with environment, hygiene and health standards should be carefully studied and based on the latest technologies, while due consideration should be given to economic and financial aspects. This resource can be used, after adequate treatment, for the irrigation of landscaping and aesthetic purposes, the irrigation of non-contact agricultural crops, and for the recharge of aquifers. However, its scope could be further expanded with the support of associated infrastructure development such as a dual water supply system (grey water use for office cooling, toilet flushing, etc.), and advanced treatment and risk control measures. The use of more advanced treatment technologies, such as carbon absorption, advanced oxidation and reverse osmosis, should be considered in order to attain high health standard security for the more extended use of treated wastewater resources, with due consideration for the economic aspects. Furthermore, consideration should be given to combining the recharge of tertiary-treated wastewater into alluvial aquifers, in combination with the development of downstream well-production fields. This will produce water supplies that have been purified through the natural processes of the aquifer for use in industrial and urban supplies and will secure strategic reserves for emergency uses.

7.2.5 Water Public Awareness and Education

Water conservation entails a complex interconnected system that includes a variety of aspects ranging from consumer education to advanced technological equipment. Water conservation includes programs and techniques designed to curb domestic, agricultural and industrial water use; wastewater reduction, treatment and reuse; supply/demand and replenishment/depletion relationships; energy consumption and environmental concerns. All aspects must be considered in relation to economic, social, religious, political, legal and aesthetic aspects.

Water conservation concepts have changed drastically from fragmented supply-oriented activities towards an approach which integrates supplier/user partnerships. Under the Dublin Statement and Agenda 21, future water conservation strategies are to integrate water conservation as a basic component of integrated water resource management focusing upon public awareness and education to guarantee the involvement of the public.

Public awareness is an essential component of water conservation programs. Therefore the cooperation of everyone, including consumers, service providers and policy-makers in designing and implementing conservation measures is essential. Both education and raising awareness are indispensable if attitudes are to be changed. To achieve greater cooperation and involvement, the public must be made to understand its water supply situation. This includes the cost of delivering water, water resource status and conservation needs, and the objectives of water conservation. The public needs to be aware of its role in conserving water resources. This should be done with consideration to the physical, biological and socioeconomic environment and to human development by using effective formal and informal methods of communication.

7.2.6 Local, regional and international cooperation and collaboration

Given increasing water scarcity, dwindling groundwater reserves and increasing reliance on non-traditional water resources development and management, it is extremely important for the Emirate of Abu Dhabi to maintain and strengthen its external links of technical and non-technical collaboration and cooperation with its neighbours and institutions within other GCC countries. This will be particularly important for issues such as the proposed development of a GCC water grid and also transboundary water resources issues which may play a much more important role in the future relationships and agreements with other Emirates and Abu Dhabi Emirate's neighbours, Saudi Arabia and the Sultanate of Oman.

7.2.7 Management of Strategic Emergency Water Resources

Currently, most of the drinking water in the Emirate is produced by means of desalination plants located on the Arabian Gulf coast. In the event of failure of supply, there is currently no adequate back up of supply (ERWDA, 2001b).

The purpose of strategic water resources, in particular, aquifer storage and recovery (ASR) schemes, is to provide an alternative storage of water in case of emergency and also to supplement existing supplies at times when there is insufficient supply to meet demands, especially in the summer months. ASR has been investigated for Abu Dhabi Emirate as early as 1998 (Hutchinson, 1998b).

The management of strategic water resources, (ASR schemes), is now the responsibility of EAD. In association with Mubadala, EAD has completed a feasibility and pilot test study in the Eastern Region and, in July, 2005, the existing ASR scheme in the Liwa region, previously managed by GTZ/ADNOC, was re-assigned responsibility to EAD. EAD are now therefore responsible for the development of both ASR schemes in Abu Dhabi Emirate.

The management of these projects is being undertaken under a committee, chaired by EAD and comprising the following members:

- EAD
- ADNOC
- ADWEA
- Dept. Atmospheric Studies, Ministry of Presidential Affairs
- Dept of Economy and Planning

The development of ASR schemes for Abu Dhabi Emirate is of strategic importance. There are two pilot projects for the strategic water reserve in Abu Dhabi Emirate. The results of the pilot tests performed in each region will be assessed before considering any full scale, operating scheme.

In the Eastern Region, the main goal of the ASR Project is to establish a large underground strategic reserve of drinking water which can be utilised in times of emergency and also to supplement the domestic water supply in the Al Ain region at times of peak summer demands. The fully implemented scheme is envisaged to develop a 30 billion imperial gallon (BIG) reserve of fresh water by injection of desalinated water from the Qidfa plant. It is expected that the final ASR well field will operate at a capacity of 20 million imperial gallons per day (MIGD) with potential expansion to 100 MIGD. The ASR will be constructed in aquifers at depths of generally less than 300 m. In the Western Region, the overall suitability of the selected ASR site was pre-determined from very detailed exploration carried out by the Groundwater Assessment Project, Abu Dhabi. (EAD, 2006). The results of the pilot tests performed in each region will be assessed before considering any full scale, operating scheme. In 2008, EAD/ADWEA joint program was started to design the full scheme project in Liwa. It is expected that the design will be finalized by mid of 2009 and construction will be finalized in mid of 2012.

8 Policies and Institutions

8.1 General Background

Water resources policy formulation in the Emirates of Abu Dhabi is confronted by number of challenges which include shortage in the natural water resources, high cost of desalinated water, and environmental degradation. In spite of all these challenges water consumption in Abu Dhabi is one of the highest per capita rates including those in water rich countries such as Canada and USA. The real challenge is not only attributed to water scarcity and the limited availability of natural fresh water resources for current uses but also to the continuous rise in the demand due to population increase, flourishing economy, and rapid rise of living standards. At the same time, the governance of the water sector is weak and characterized by institutional fragmentation leading to duplication of effort, ineffective control and management and also wasted resources.

The water resources report published in 2006 provided a comprehensive review of the water resources in the Emirate of Abu Dhabi. The report defined all water sources and users up to the year 2006, highlighted problems associated with current water management practices, and provided an outlook for future practices in water resources management in the Emirate. The outlook underlined the need to continuously study and complete Master Plans with associated activities and programs for all water use sectors including domestic and bulk water supply (from both desalination and groundwater), agriculture (largely from groundwater) and amenity plantation (mixture of groundwater, desalinated water, and treated waste water). A year later the Environment Agency- Abu Dhabi (EAD) issued the Strategic Plan 2008-2012 which mapped out 10 Priority Areas and defined specific strategies to achieve the identified targets for each priority area. Water came at the top of this agenda.

The Strategic Plan (2008 – 2012) of EAD recognized the following water related challenges among others:

- As in all arid countries, water is a scarce commodity in the Emirate of Abu Dhabi. Abu Dhabi Emirate has less than 100 mm rainfall per year, and a low groundwater recharge rate of less than 4% of total annual water used. The water is mostly saline and brackish groundwater, with only 3% fresh water. There are no reliable, perennial surface water resources.

- Abu Dhabi currently has one of the highest per capita water consumption rates in the world. Rapid social and economic development over the last four decades has led to water scarcity, groundwater depletion, and potential for pollution. (especially nitrates from the extensive use of inorganic fertilizers)

- The groundwater level in Abu Dhabi Emirate has declined significantly because of uncontrolled drilling of wells. The exponential reduction in groundwater levels over the last years is largely caused by an increase in human activities. Nitrate levels in groundwater exceed drinking water guidelines for a bulk of the groundwater. Exposure to high levels of nitrate represents a health risk.

- Desalinated sea water is now the main source of drinking water. Unsustainable water consumptions- Abu Dhabi Emirate's daily water consumption rate of 550 liters per person is one of the world's highest domestic water consumption rates.

- Saline groundwater has increasingly been used for irrigation. Soil salinity has increased to the extent that, in many areas, only a few salt-tolerant crops are now grown (i.e., Rhodes grass and dates). Excessive and improper use of inorganic fertilizers by farmers has also resulted in widespread nitrate leaching and contamination of the groundwater.

Detailed Master plans have already been developed in the past for domestic water supply and also for treated wastewater. A master plan for groundwater development is still lacking particularly for its use in agriculture and forestry sector. This is now the responsibility of EAD to develop them following a participatory approach where the users and other stakeholders should be fully involved.

As most of the drinking water in the Emirate is currently produced by means of desalination plants located on the Arabian Gulf coast, there is high risk of adequate back up source of supply in the event of failure of their supply. A strategic water resources plan to provide an alternative for drinking water is extremely important if the desalination plants stop their operations under a state of emergency. Aquifer Storage and Recovery (ASR) Scheme for Abu Dhabi has been investigated in 1998. In association with Mubadala, EAD carried out a feasibility and pilot test study in the eastern region. The scheme aims at recharging groundwater aquifers with piped desalinated water produced from the newly constructed desalination plant at Qidfa. A similar ASR pilot scheme has just been completed in the Liwa region.

State-of-the art waste water treatment plants have been developed and expanded to treat and reuse the treated wastewater in irrigation of green areas in the Emirate. In 2002, a very comprehensive assessment and review of the treated sewage effluent transmission, distribution system and irrigation management was conducted for Abu Dhabi Island which provided firm recommendations on the work required to meet the growth in demand of water for irrigation to the year 2020. The report concluded that the landscape currently irrigated with treated effluent cover an area of approximately 17 km2 of Abu Dhabi Island which is predicted to increase to 22 km2. The assessment of irrigation water quantity showed that insufficient supply of treated sewage effluent to meet current and future demands. It is striking to know that only 17% of the total used quantity of domestic water is treated. The balance is attributed to leakage from the transmission network.

8.2 Water Sector Governance Structure and Institutional Arrangements

Since there no single authority for the mandate for water resources management, water resources development followed in the past unplanned efforts characterized by duplication and led to wasted resources. Responsibility for production and distribution of drinking water is vested within Abu Dhabi Water and Electricity Authority (ADWEA) which was established in 1999. There are now eight production companies responsible for generation of electricity and the desalination of water. Five of these companies are privately operated and partly owned by foreign investors. All electricity and water output is sold to single buyer; the Abu Dhabi Water and Electricity Company (ADWEC). Transmission and dispatch of all water and electricity through the Emirate is the responsibility of Abu Dhabi Transmission and Dispatch Company (TRANSCO). Distribution and supply of water and electricity to final customers is the responsibility of Abu Dhabi Distribution Company (ADDC) and Al Ain Distribution Company (AADC). It can be easily noticed that the group of companies including TRANSCO, ADDC, and AADC are natural monopolies since ADWEC is the single buyer. As a result, these companies are subject to price controls which limit their profits and set performance standards so as to protect the rights of customers who do not have a choice in choosing the service provider. The Regulation and Supervision Bureau (RSB) was set as the independent regulator of the water and electricity sector. The RSB is empowered by Law No (2) of 1998. In 2005, the RSB was also given responsibility for the regulation of sewerage services throughout the Emirate.

In 2005, the newly formed Environment Agency of Abu Dhabi (EAD) was assigned total responsibility for ground water management. EAD's main focus at present is on regulation of groundwater use, the development of a groundwater resources monitoring system and establishing a water information network through a centralized water resources database. In late 2005, EAD established a groundwater monitoring network and in April, 2006, work commenced on the development of a comprehensive water resources database in the Emirate.

8.3 Water Laws and Regulatory Framework

Lack of regulation and control on the development and use of water resources has been considered as the main reason for the current gloomy water situation especially on water use for agriculture. Policies, standards and laws on regulating the use of treated wastewater for various purposes are yet to be developed including use of treated effluent for enhanced recharge of groundwater aquifers or irrigating crops for human consumption.

As a major step towards controlling groundwater development, a water well drilling Law (Law No 6) was issued in March 2006 and the well permitting policy is managed by EAD. The law consists of 26 articles. Among others, the Law:

- Stipulates that a license must be obtained from EAD before carrying out any works In drilling new wells, deepening an existing well, increasing well's diameter, boosting water recovery by using a pump, replacing an old well, transporting or selling well's water.
- Specifies provision for obtaining the license for well drilling and the license for practicing well drilling works and that drilling license applications must be submitted by the well owner who shall enclose all required document along with the application.
- States that approval or rejection of the application shall be sent in a written and registered notification to the applicant. The applicant possesses the right to appeal the decision to the EAD Secretary General within thirty days of notification and that licensee shall adhere to the plan, design and technical specifications decided by the concerned department, namely the Water Resources Department at the EAD. According to the law, duration of the license for well drilling work shall be two years.
- Binds owner to maintain farm wells, pumps, meters, pipes and irrigation conduits. Contractors who practice well drilling works without license shall be imprisoned for no less than three months and no more than one year and/or fined DH 10,000 to DH 50,000.
- Specifies Penalties for other violations by both contractors and owners. Owners must notify EAD for any wells dug before issuance of this law by filling up a special form.
- Grants EAD employees powers to access any land, farm, or facility to conduct research or to collect data on deep water resources, provided that the owner of the land, farm or facility shall be notified prior to the visit.

8.4 Bridging the gaps

8.4.1 Improved water policies

The future policy for improved water management in Abu Dhabi has to shift gradually from "supply management" to demand management in the context of integrated water resources management where water conservation becomes the key issue in all water use sectors. It is believed that in water scarce countries, the best additional source of water is the water that can be saved from the existing demand sectors. At the same time recycling and reuse of wastewater became a well regulated practice to maximize the benefits of the limited available resources. Saving water rather than the development of non-conventional water resources often remains as the optimum water policy that satisfy economic development and environmental sustainability on the long run. Demand management requires a set of actions that would influence the water use behavior in every water demand sector. It should be recognized that invitation for demand management and water saving in any water use sector does not and should not mean reduction in the level of service. On the contrary, they require high use efficiency, better management and improved technologies which increase reliability of the service provided.

Water conservation policy should focus on the agricultural sector being the biggest water consuming sector. Agricultural development should be limited to low water demanding and salt tolerant crops. Modern irrigation systems should be implemented at a wider scale. This is an area where incentives and perhaps subsidies should be provided to encourage water saving. Agriculture should be based on economic feasibility and cost of water be introduced as an important element in the economic assessment of agricultural projects. With the scarcity of the natural water resources in the Emirate and the high cost of desalination the overall cost of crop production might be significantly higher than the cost of importing the same crop. Imported crops and food product are equivalent to importing the same volume of water "Virtual Water" used in their production. Crop production should be limited to crops where there is a comparative advantage in producing them locally. Drilling of new groundwater for irrigation in stressed aquifers should not be allowed. As a general policy, restrictions should be imposed on the allowed volume of water pumped for agriculture by setting a maximum for unit area and any additional pumping would be subject to fines.

Although it is claimed that crop production has a social dimension for the rural communities in Abu Dhabi Emirate, important changes in the agricultural policy is required. Agricultural and Greenery policies need to be revisited on the basis of water availability and sustainability. A first step has been taken by not allowing new extension of agricultural lands. The agricultural policy should be reviewed to consider actions that lead to significant changes which lead to reduction in water consumption in the sector. Similarly, the efficiency of irrigation systems in the forestry and amenity sectors should be evaluated and improved to minimize the losses. Shift should be made towards indigenous trees and shrubs which are less water consuming and can tolerate the climate of the country. Since the area currently under forests is beyond the sustainable limit, one of several decisions need to be made; either to continue the current level of forestry until irrigation becomes impractical or to significantly reduce the area of forestry towards sustainable level or to find ways of reducing significantly the water required to sustain each hectare of forest, or a combination.

In the domestic sector, it is believed that much of the municipal water supplies are lost before it reaches the consumers through leakage from the supply and distribution systems. This is an area where there is great potential for better conservation of water in this sector. The high consumption rates at the household should be lowered to at least the world average as a first step. Pricing of municipal water should be oriented to promote conservation. The high per capita consumption of domestic water generates a lot of wastewater, however, only small portion of the domestic water return to the sewerage system. Leakage from the collection system is suspected to be high. It should be assessed and correction measures should be taken. It is not only saves water which is an important asset, but also prevents groundwater pollution.

Public awareness is a very essential for water conservation and reduction of wastage in the domestic sector. There is a need to establish a water resources strategy in Abu Dhabi Emirate as well as policies to increase awareness about water conservation particularly within the agricultural sector. ADWEA, in association with EAD, and NGOs within the UAE have continued to participate in schemes which actively encourage the rationalization of water use at the households. More of these schemes are still required and should be based on transparency of information and making the public aware of the risks involved in wasteful use of the limited resources. In education, water conservation and saving should become a basic knowledge that children in the primary school learn and practice.

Investments in water resources conservation and water saving technologies and practices should be an integral part of the master plan for achieving water security. Policy options and investment interventions should be identified, agreed upon, and implemented through a participatory process and agreement between the stakeholders including the costs, benefits, and trade-offs. Stakeholder participation in water resources planning is essential for coordination, optimization of resources, promoting the principles of the conservation and efficiency, ensuring ownership, and achieving sustainable development. Improved information and knowledge about water supply and demand on basis of near accurate projection of population is a basic need for proper planning of water resources management including new investment in the water sector

The development of ASR schemes for Abu Dhabi Emirate is of strategic importance. The promising results of the pilot schemes in the eastern and Liwa regions should be subject to further evaluation and assessment. If proved to be technically, economically, and environmentally feasible, full scale operating schemes should be considered.

The wastewater collection and treatment infrastructure should be expanded to meet the future demands. The resulting treated effluent should be considered as valuable resource which can fill gaps id demand especially in irrigation. Treated wastewater at the level similar to the one practiced in Abu Dhabi has been used in other countries for recharging groundwater' irrigating orchards and even used for drinking (Singapore). It is imperative to give treated wastewater more attention and an assessment of the efficiency and treatment facilities should be carried out.

8.4.2 Improved governance and Institutions

To address the governance and institutional problems in the water sector, a distinction should be made between managing the resource and the management of services. Resource management is a matter of national security where economic growth, livelihood and sustainable development are inseparable elements. A central body usually is in place in most countries for policy development, overall planning of water resources allocation and management, regulation and control, monitoring and information management and research and studies. This type of agency does not yet exist in Abu Dhabi. However, it has been proposed by EAD to establish a new independent Water Management Authority (ERWADA 2004) to spearhead and coordinate the management of the water resources of the Emirate of Abu Dhabi. This was a wise thinking which should not be ignored or further delayed any more to ensure the holistic approach for integrated water resources management in the Emirate. It is important to recognize that this does not imply that the water service agencies have to fall under the responsibility of such Central Authority. Most important is that the responsibility of general planning and coordination is taken over by one Authority which becomes accountable for medium and long term planning and management of water resources. This agency shall carry out the regulatory and control functions of water resources management from all sources (groundwater, desalination, and treated wastewater) by all water use sectors (domestic, industrial, industrial and environment). Regulation to ensure quality and efficiency of services would remain with independent regulatory bodies such belonging to the concerned sector as in the case of the Regulation and Supervision Bureau (RSB) for regulation of drinking water supply and sewerage services.

There is now a real opportunity to implement effective reorganization of the water sector if an effective overall strategy for integrated water resources management within the Emirate of Abu Dhabi is to be developed and implemented. While the proposed agency should focus on central planning it should promote decentralized management. The initiative taken by EAD to establish regional offices for groundwater management presents a good model for decentralization. The proposed Central Water Resources Management Authority should be the home and manager of a central GIS-based Water Resources Monitoring System. The Emirate wide Groundwater Monitoring System recently developed by EAD will form the core part of the Central Water Resources Monitoring System. All water sub-sectors and water agencies should share their information with the Central Monitoring system. They should continue to update their data basis. In sectors where there is little or no systematic measurement or monitoring of water resources parameters, they should begin effort to develop their monitoring networks which shall be an integral part of the State wide Monitoring System. The Central Water Resources Management Authority should ensure a high quality assurance for the respective data and timely communicate them to decision makers. It is also essential that the Central Authority share the combined data and information on regular basis with the water managers and users throughout the Emirate. The outcome will be enhanced planning and management of the water resources on sound basis and better knowledge of the situation on ground. Annual report on the state of water resources will be prepared and presented to The management of a strategic water resources reserve should be also the responsibility of the Central Agency.

It is proposed to take advantage of the capacity built within EAD in groundwater water resources at the Emirate level to expand its authority to the overall water resources management in Abu Dhabi. Another comparative adntage for mandating EAD to carry out the Water resources management functions (see section 4), is to maintain the linkage between water abd environments. The Groundwater Resources Management Departed since its establishment in 2005 carried out increasing responsibilities and proved efficient enough to take the full responsibility of water resources in the Emirate. This would allow faster shift to integrated water resources management rather than establishing new agency. Time will tell, if it will be necessary that one day the Water Resources Management Division of EAD should become independent agency.

8.4.3 Improving the legal and regulatory frameworks

An Emirate wide legal and regulatory framework (laws and by-laws) of water resources management is needed with operational capacity and mechanisms for enforcement. Only an agency with overall water resources management responsibilities will be capable to prepare issues and enforce such legal framework. The law will ensure consistency in using water by all sectors and will ensure overlaps, conflicts and ambiguity in dealing with water from the source to the users and back to treatment or disposal.

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D. ABBREVIATIONS

AADC	Al Ain Distribution Company
ADDC	Abu Dhabi Distribution Company
ADIAS	Abu Dhabi Island Archaeological Survey
ADNOC	Abu Dhabi National Oil Company
ADWEA	Abu Dhabi Water and Electricity Authority
ADWEC	Abu Dhabi Water and Electricity Company
AED	Arab Emirates Dirham
AGFUND	Arab Gulf Fund for Support of United Nations Programmes
ASR	Aquifer Storage and Recovery
Bm^3	Billion Cubic Meters
BOD	Biological Oxygen Demand
BOO	Build, Own and Operate
BOT	Build-Own-Operate
DEWA	Dubai Electricity and Water Authority
DOC	Dissolved Organic Carbon
FEA	Federal Environmental Agency
EAD	Environment Agency Abu Dhabi
EEG	Emirates Environment Group
ENG	Emirates National Grid
ERWDA	Environmental Research and Wildlife Development Agency
FEWA	Federal Electricity and Water Authority
G	Gallon
GCC	Gulf Cooperation Council
GD	Gallon per Day
GDP	Gross Domestic Product
GTZ	Deutsche Gesellschaft fűr Technische Zusammenarbeit
GWAP	Groundwater Assessment Project Abu Dhabi
GWRP	Groundwater Research Program
ha	Hectare
ICBA	International Center for Biosaline Agriculture
IG	Imperial Gallon
IGD	Imperial Gallon per Day
IWP	Independent Water Producer
IWPP	Independent Water and Power Producer
IWRM	Integrated Water Resource Management
m^3	Cubic Meter
mamsl	Meters Above Mean Sea Level
MEW	Ministry of Environment and Water
MED	Multi Effect Distillation
MG	Million Gallons
MIG	Million Imperial Gallons
MIGD	Million Imperial Gallons per Day
Mm^3	Million Cubic Meters
MNEP	Ministry of National Economy & Planning
MRMEW	Ministry of Regional Municipalities, Environment, and Water (Oman)
MSF	Multi Stage Flash
NDC	National Drilling Company
Mya	Million years ago
O&M	Operation and Maintenance
PWL	Pumping water level
PWPA's	Power and Water Purchase Agreements
RO	Reverse Osmosis
RSB	Regulation and Supervision Bureau
SEWA S	harjah Electricity and Water Authority
SPC	Sewerage Projects Committee
SWL	Static Water Level
STP	Sewage Treatment Plant
TDS	Total Dissolved Solids
TSE	Treated Sewage Effluent
TRANSCO	Transmission and Despatch Company
UAE	United Arab Emirates
UFW	Unaccounted for Water
UWEC	Union Water and Electricity Company
USGS	United States Geological Survey
WPRC	Water and Electricity Research Center
WWTP	Waste Water Treatment Plant
YBP	Years before present

E. CONVERSION MEASURES

1 m3 = 220 Imperial Gallons (IG)

1 IG = 0.045 m_3

1 m3 = 264 Gallons (G)

1 G = 0.0038 m_3

1 IG = 1.2 G

1 Ha = 2.47 Acres

1 Acre = 0.405 Ha

1 Liter = 0.264 Gallons

1 G = 3.785 Liters

1 IG = 4.54 Liters

F. GLOSSARY OF TERMS

ABSTRACTION — The removal of water from a groundwater reservoir, usually by pumping. [L3/T] m3/d, m3/a.

ACTUAL EVAPOTRANSPIRATION — The proportion of **Potential Evapotranspiration** that is actually evapotranspired under the prevailing soil moisture conditions. [L] mm.

AFLAJ — Plural for FALAJ (see **FALAJ)**

AGRICULTURAL DRAINAGE WATER — The water withdrawn for agriculture but not consumed and returned.

ALLUVIAL DEPOSITS — The general name for all sediments, including clay, (**ALLUVIUM**) silt, sand, gravel or similar unconsolidated material deposited in a sorted or semi-sorted condition by a stream or other body of running water, in a stream bed, floodplain, delta or at the base of a mountain slope as a fan.

ANISOTROPIC — An aquifer which has direction-dependant properties. See **Isotropic**.

AMBIENT GROUND WATER FLOW — The rate of flow and direction of flow of ground water under unpumped, natural conditions.

ALLUVIAL FANS — A fan shaped deposit of detrital material deposited by a stream where it emerges from a steep mountain slope or from an upland onto a less steeply sloping terrain.

ANION — A negative electricity charged ion such as a nitrate or chloride ion.

ARGILLACEOUS— Adjective to describe a sedimentary rock made predominately of indurated clay particles

AQUICLUDE — A geolgical stratum or formation that may be capable of storing water but is unable to transmit it in significant amounts.

AQUIFER — An aquifer is a formation, group of formations or part of a formation containing enough saturated permeable material to produce significant amounts of water to wells and springs.

AQUIFER DEPLETION — Aquifer depletion occurs when ground water is withdrawn from an aquifer at a rate greater than it can be replenished.

AQUIFER STORAGE & RECOVERY (ASR) — Aquifer Storage and Recovery (ASR) involves injecting water into an aquifer through wells or by surface spreading and infiltration and then pumping it out when needed.

AQUIFER TEST — A pumping or injection test involving the withdrawal of water from, or addition of water to, a well at measured rates and the measurement of resulting changes in head in the aquifer via one or more piezometers or observation boreholes both during and after the period of discharge or addition with a view to determining the hydraulic properties of the aquifer in the vicinity of the well.

AQUIFER VULNERABILITY — A measure of how vulnerable an aquifer is to contamination.

AQUIFER VULNERABILITY MAPPING — Mapping the vulnerability of an aquifer to contamination from sources. Vulnerability mapping does not consider the type of land use above an aquifer, only the intrinsic vulnerability of the aquifer, typically based on the type, thickness, and extent of geologic materials overlying an aquifer, depth to water, and type of aquifer materials.

AQUIFUGE — A geologic formation that is both impermeable and contains no water.

AQUITARD — A geological stratum or formation that is able to contain water but can only transmit it at very slow rates.

ARTIFICIAL RECHARGE —The deliberate act of adding water to a groundwater aquifer by means of a recharge project; also, the water so added. Artificial recharge can be accomplished via injection wells, spreading basins, dams or in-stream projects.

ARTESIAN AQUIFER — See Confined Aquifer.

ARTESIAN WELL — A well obtaining its water from an artesian or confined aquifer in which the water level in the well rises above the top of the aquifer. The water level in a flowing artesian well rises above the land surface.

BARCHAN DUNE — an arc-shaped sand ridge, comprised of well-sorted sand.

BASEFLOW The sustained low flow in a stream.

Generally base flow is the inflow of ground water to the stream.

BEDROCK — Rock underlying soil and other unconsolidated material.

BRACKISH — Water quality in between Fresh and Saline

CAPTURE ZONE — The land area that contributes ground water to or recharges a pumping well.

CATION — A positive electrically charged ion such as a sodium or calcium ion.

CATCHMENT — A surface from which runoff is collected. Examples include roofs, paved surfaces, or constructed surfaces covered with plastic.

CHANNEL — The bed of a river, stream, drainage ditch, or other waterway that transports a concentrated flow of water.

CLASTIC ROCK (DETRITAL ROCK) — A sedimentary rock composed of fragments of pre-existing rocks or organic structures.

CLIMATE — Fluctuating aggregate of atmospheric conditions characterised by the state and the developments of the weather in a given area.

COEFFICIENT OF STORAGE — See Storage Coefficient.

CONCENTRATED FLOW — Runoff that accumulates or converges into well-defined channels.

CONE OF DEPRESSION — A depression in the potentiometric surface in the area around a well, or group of wells, from which water is being withdrawn.

CONFINED AQUIFER — Confined is synonymous with artesian. A confined aquifer or an artesian aquifer is an aquifer bounded both below and above by beds of considerably lower permeability than that existing in the aquifer itself. The ground water in a confined aquifer is under pressure that is significantly greater than that existing in the atmosphere.

CONFINING BED — A bed of impermeable material stratigraphically adjacent to one or more aquifers. Confining bed is now used to replace terms such as “aquiclude”, “aquitard” and “aquifuge”.

CONSOLIDATED FORMATION — See Formation.

CONSUMPTIVE USE — Water that has been evaporated, transpired, incorporated into products, plant tissue, or animal tissue and, therefore, is not available for immediate reuse. Sometimes referred to as water consumption.

CONTAMINANT — Solute which, through human action, intrudes into the hydrologic cycle.

CONTAMINANT PLUME — Contaminants which encroach into a ground water system are moved down gradient. The area of the aquifer containing the degraded water which resulted from the migration of a pollutant is called a contaminant plume.

CONTAMINATION — Impairment of natural water quality by chemical or bacterial pollution as a result of human activities. The degree of contamination allowed before an actual hazard to public health is created will depend upon the intended end use, or uses of the water.

CONVENTIONAL WATER RESOURCES — Naturally occurring water resources, either above or below ground level.

CRETACEOUS — The most recent geologic period in the Mesozoic Era, 145 to 65 million years ago.

CROP WATER REQUIREMENTS — The total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate regime, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield.

CROP YIELD — The harvested production per unit of harvested area for crop products

DAM — A barrier across flowing water that obstructs, directs or retards the flow, often creating a reservoir, lake or impoundment.

DEEP PERCOLATION — The downward movement of water through the soil below the plant root zone.

DEMAND MANAGEMENT — The programme adopted to achieve effective management of the use of water resources

DESALINATION — Process of removal of salts from either sea-water or saline / brackish groundwater / surface water.

DESALINATED WATER — Fresh water generated by desalination of sea or brackish waters (annually estimated on the basis of the total capacity of water desalination installations).

DIFFUSED WATER — Water, usually resulting from rainfall and/or snow melt, that spreads over the land surface. Once diffused water enters a well defined channel, it is usually described as concentrated flow.

DIVERSION — A channel constructed across the land slope to intercept surface runoff and to conduct it to an outlet.

DISCHARGE AREA — An area where ground water and water in the unsaturated zone is released to the ground surface, to surface water or to the atmosphere.

DRAINAGE — The removal of excess water from the land surface and/or from the soil profile.

Surface Drainage The diversion or orderly removal of excess water from the surface of the land by means of improved natural or constructed channels, supplemented when necessary by the sloping and grading of land surfaces to these channels.

Subsurface Drainage The removal of excess water from the soil profile by means of drain tiles, perforated pipes, or other devices.

DRAINAGE AREA — A general term for the land area drained by a ditch, creek, stream, or river. When reference is made specifically to a large surface water body like a river, the term Drainage Basin is used.

DRAWDOWN — The variation in the water level in a well prior to commencement of pumping compared to the water level in the well while pumping. In flowing wells drawdown can be expressed as the lowering of the pressure level due to the discharge of well water.

DRILLED WELL — A well that is constructed with a drilling rig, such as an air rotary or cable tool drilling rig.

DUG WELL — A well that is dug by hand or excavated by backhoe. Dug wells are usually shallow.

EFFECTIVE AQUIFER THICKNESS — The saturated thickness of an aquifer over which groundwater flow is significant. [L] m.

EFFECTIVE POROSITY — For both confined and unconfined aquifers, the proportion of interconnected porespace which will yield water under gravity (drainable pore space or **Specific Yield**). [D].

EFFECTIVE RAINFALL — Is that proportion of rainfall that is available for run-off and groundwater recharge after satisfying actual evaporation and any soil moisture deficit that might have developed. [L] mm.

EFFLUENT — Diffuse groundwater seepage into a surface water feature (a gaining situation).

ELECTRICAL CONDUCTIVITY (EC) —A measure of how well a material accommodates the transport of electric charge. For groundwater, it is directly measured and usually reported in µS/cm.

EPHEMERAL — A stream or spring that only flows in times of high groundwater level. (See also **Intermittent**).

EROSION The detachment and movement of soil and rock particles by gravity, wind, water, freezing and thawing, and/or other natural phenomena.

EQUIPOTENTIAL LINE — A line along which the groundwater potential is the same. Effectively a contour line of the water table or piezometric surface. Fluid flow is normal to the equipotential lines in the direction of decreasing groundwater potential.

EVAPORATION — The process by which water is converted from a liquid to a vapour by the application of energy. Evaporation can take place from a wet soil surface, from snow, ice and open water bodies and from vegetation wetted by rain. In addition, vegetation conveys water from the soil to the atmosphere by evaporation mainly through the stomata in the leaves - a process known as **Transpiration**. [L] mm.

EVAPORITE — water-soluble, mineral sediments that result from the evaporation of saline water.

EVAPOTRANSPIRATION — Loss of water from a land area through transpiration of plants and evaporation from the soil.

FALAJ — An ancient means of transporting water in channels, both surface and sub-surface, used in the Midedle East until today for irrigation of agriculture and town and village water supply

FAULT — A fracture in the earth's crust along which dislocation has taken place so that the rocks on one side of the fault have been displaced in relation to those on the other side.

FLOODPLAIN — The flat land adjacent to a river, formed by deposition of fluvial materials.

FLOOD IRRIGATION — All types of irrigation which make use of rising water from flood for inundating areas without major structural works, e.g. flood recession, spate irrigation and wild flooding

FLOW LINES — Lines indicating the direction of groundwater movement. Flow lines are perpendicular to **equipotential lines**.

FLOWING ARTESIAN WELL — A well where the water level is above the ground surface.

FLUVIAL DEPOSITS — Deposits related to a river or stream.

FOSSIL GROUNDWATER — Old groundwater which currently receives no recharge

FORMATION (GEOLOGIC) — The two basic types of geologic formations are defined below:

Consolidated A homogeneous layer composed of solid rock or cemented earthen material.

Unconsolidated A formation composed of loose, unsorted earthen materials, or particles such as clay, silt, sand, gravel, or stones.

FRACTURE — A break or crack in the bedrock.

FRESH WATER — water which generally has a TDS content of less than 1500 mg/l

FRESH WATER - SALT WATER TRANSITION ZONE — The interface zone occurring between fresh water and saltwater underlying marine islands and coastal areas with ground water occurring below the surface of the ground in geologic formations under saturated conditions.

GEOLOGIC FORMATION — See Formation

GEOMORPHOLOGY — Geomorphology is the science dealing with the origin and evolution of land forms.

GROUNDWATER — Water in the zone of saturation, that is under a pressure equal to or greater than atmospheric pressure.

GROUNDWATER CATCHMENT AREA — An area contributing natural replenishment (recharge) of the ground water regime. It may include localized discharge areas.

GROUNDWATER DIVIDE — The uppermost boundary of a ground water basin.

GROUNDWATER MINING — Permanent depletion of ground water reserves.

GROUNDWATER POTENTIAL — A term used to describe both the piezometric head in a confined aquifer and the elevation of the free water surface in an unconfined aquifer. [L] m.

GROUNDWATER TABLE — That surface below which rock, gravel, sand or other material is saturated. It is the surface of a body of unconfined ground water at which the pressure is atmospheric.

HAND DUG WELL — see **DUG WELL**

HARDNESS — When hard water is used with soap it will form an insoluble residue and hard water will form a scale in utensils in which the water has been allowed to evaporate. Hardness is mainly caused by calcium and magnesium ions. Hardness is generally expressed in mg/L calcium carbonate (Ca CO3).

HETEROGENEOUS DEPOSIT — Non-uniform structure and composition throughout the deposit.

HOMOGENEOUS DEPOSIT — Structure or composition of the deposit is uniform throughout.

HYDRAULIC CONDUCTIVITY — Hydraulic conductivity is a measure of the ability of a fluid to flow through a porous medium determined by the size and shape of the pore spaces in the medium and their degree of interconnection and also by the viscosity of the fluid. Hydraulic conductivity can be expressed as the volume of fluid that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

HYDRAULIC GRADIENT — The slope of the ground water level or water table.

HYDRAULIC HEAD — The level to which water rises in a well with reference to a datum such as sea level.

HYDROGEOLOGY — Study of ground water in its geological context.

HYDROGRAPH — A graphical plot of changes in elevation of water or flow of water with respect to time.

HYDROLOGIC CYCLE — The continued circulation of water between the ocean, atmosphere and land is called the hydrologic cycle.

HYDROLOGY — The science dealing with the waters of the Earth, their distribution and movement on the surface and underground, and the cycle involving evaporation and precipitation (Hydrologic Cycle).

HYPERSALINE — With salinity of greater than sea water

IGNEOUS ROCKS — Rocks that solidified from molten or partly molten materials, that is from a magma or lava.

IMPERMEABLE — Impervious to flow of fluids.

IMPERMEABLE LAYER — A layer that does not permit water to flow through it.

INCRUSTATION — Mineral matter deposited by water. One of the major causes of well failure is the chemical and biological incrustation of well screen through precipitation of calcium and magnesium carbonates or sulphate's. The precipitation of iron and manganese compounds and slime producing iron bacteria will also plug well screens.

INDURATED — A compact rock hardened and solidified by post depositional chemical and physical alterations.

INFILTRATION RATE — The rate at which water permeates the pores or interstices of the ground.

INFILTRATION COEFFICIENT — The proportion of **Effective Rainfall** that infiltrates as groundwater **Recharge**. [D].

INFLUENT — Infiltration of surface water through the streambed as a source of recharge to groundwater (a losing situation).

INTERBED — A lens or layer of material within an aquifer that has different characteristics.

INTERCEPTION LOSSES — The difference between the incidence of gross rainfall and the sum of throughfall and stem flow; largely due to direct evaporation from the tree canopy. [L] mm.

INTERFLOW — The lateral movement of a significant amount of water through the soil above the regional water table.

INTERMITTENT — A stream that simultaneously has both flowing and dry reaches at various locations along its length. (See **Ephemeral**).

INTRISIC PERMEABILITY — See **Permeability**.

ISOTOPE — An atom of element having a different nuclear mass and atomic weight from other atoms in the same element.

ISOTROPIC — Exhibiting properties with the same values in all directions.

JEBEL — Arabic expression for mountain or hill

LACUSTRINE DEPOSITS — Sediments laid down in a lake. Includes gravelly deposits at the margin and clay in deeper water. Sediments commonly show seasonal banding or varve clays.

LEACHATE — Fluid percolating through a land fill.

LEAKY AQUIFER — An aquifer that is overlain or underlain by a semi-permeable strata from or into which groundwater can flow.

LEVEL OF GROUND WATER DEVELOPMENT — The level of ground water use of an aquifer relative to the aquifer's ability to replenish itself.

LITHOLOGY — All the physical properties, the visible characteristics of mineral composition, structure, grain size etc. which give individuality to a rock.

MARINE DEPOSITS — Mostly silt and clay materials deposited under a marine environment.

MEDIAN — Being in the middle or in an intermediate position.

MESOZOIC — Geologic era preceding the Cenozoic Era. The Mesozoic Era was a time when the rocks of the Triassic, Jurassic and Cretaceous Systems were deposited. 248 to 65 million years ago

METAMORPHIC ROCKS — Any rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the earth's crust.

MODERN IRRIGATION— Use of new, efficient irrigation technology e.g drip, sprinklers, bubblers, spray etc

MONSOON— A seasonal wind of S.E.Asia associated with very heavy rainfall

MOTHER WELL — Source well water for Daudi type falaj

MULTI AQUIFER — A hydrogeological situation where several aquifers exist within a formation which are largely independent of each other because they are separated by an **Aquiclude** or **Aquitard**.

NON-CONVENTIONAL WATER RESOURCES — Total volume of water obtained through the development of new technologies. The non conventional resources considered will be water generations (productions) that comes either from the desalination of sea and brackish waters, or the waste water regeneration for reuse.

NON-RENEWABE WATER RESOURCES — Non renewable water resources are not replenished at all or, for a very long time by nature. Generally, they are aquifer sources which have a negligible rate of recharge and thus can be considered non renewable.

OASIS — An area of traditional palm trees and agriculture irrigated by means of aflaj and wells

OBSERVATION WELL — A well constructed for the objective of undertaking observations such as water levels, pressure readings and ground water quality.

OPEN UNCONFINED AQUIFER — An unconfined aquifer with little or no overlying low permeability material.

OROGENY — The deformation of the earth's crust to form mountains.

OVERBURDEN — The layer of fragmental and unconsolidated material including loose soil, silt, sand and gravel overlying bedrock, which has been either transported from elsewhere or formed in place.

OVERDRAFT — The reduction of ground water storage that occurs when withdrawals from an aquifer exceed recharge. Sometimes referred to as mining of ground water.

OVERLAND FLOW — The quantity of water that moves across the land surface. Contributions to overland flow are from runoff and from the surfacing of subsurface flows before they reach a receiving stream or a defined drainage channel.

PALEOCENE — A geological epoch , 65 to 55.5 million years ago

PALAEOZOIC — Geological era preceding the Mesozoic Era. The Palaeozoic is a major division of geologic time and it includes in descending order the Permian, Carboniferous, Devonian, Silurian, Ordovician and the Cambrian.

PERCHED WATER TABLE — A separate continuous body of ground water lying (perched) above the main water table. Clay beds located within a sedimentary sequence, if of limited aerial extend, may have a shallow perched ground water body overlying them.

PERCOLATION — The downward movement of water through layers of soil or rock.

PERENNIAL — A stream or spring flowing throughout the year.

PERMEABILITY — The capacity of a rock, sediment, or soil to transmit a fluid; it is a measure of the relative ease of fluid flow under a **Hydraulic Gradient**. Commonly taken to be synonymous with the term **Hydraulic Conductivity** which implies the fluid is water. **SPECIFIC** or **INTRINSIC Permeability** is a function only of the porous medium. [L2] millidarcys.

PERMEABLE — The property of a porous medium to allow the easy passage of a fluid through it.

pH — A numerical measure of the acidity or alkalinity of water ranging from 0 to 14. Neutral waters have pH near 7. Acidic waters have pH less than 7 and alkaline waters have pH greater than 7.

PHYSIOGRAPHY — Physical geography.

PIEZOMETER — Pressure reading and measuring instrument connected to a short sealed off length of a drill hole or hydrogeologic unit.

PIEZOMETRIC SURFACE — Imaginary surface defined by the elevation to which water will rise in wells penetrating confined aquifers.

PIEZOMETRIC HEAD. The water pressure in a **Confined Aquifer**. The level to which groundwater will rise in an observation borehole drilled through the impermeable (confining) layer. [L] m.

PLATEAU — An elevated land surface of large areal extent where the surface is nearly level.

PLEISTOCENE — The period following the Pliocene, 1.8 to 8,000 years ago

PLIOCENE — Geological epoch, 5.3 to 1.8 million years ago

POLLUTION — Contamination of the environment with objectionable or offensive matter.

POLLUTED WATER — Water containing a natural or human-made impurity. The water is classified as polluted when the concentration of the pollutant exceeds the acceptable standard for a particular use. Water that contains disease-causing or toxic substances is said to be contaminated.

POROSITY — The volume of openings in a rock, sediment or soil. Porosity can be expressed as the ratio of the volume of openings in the medium to the total volume.

POTABLE WATER — Water that is safe and palatable for human consumption.

POTENTIOMETRIC SURFACE — The level to which water rises in a tightly cased well constructed in a confined aquifer. In an unconfined aquifer, the potentiometric surface is the water table. The term piezometric is sometimes used in place of potentiometric.

POTENTIAL EVAPOTRANSPIRATION — The amount of water that would be lost from the ground surface by **Evaporation** and **Transpiration** if sufficient water were available in the soil to meet the demand. [L/T] mm/a.

POTENTIAL WELL YIELD — An estimate of well yield generally above the existing yield rate or test rate, but considered possible on the basis of available information, data and present well performance.

PRECIPITATION — The process by which water vapor condenses in the atmosphere or onto a land surface in the form of rain, hail, sleet or snow.

PUBLIC INVOLVEMENT — The process by which the views of all parties interested in a proposed government decision are integrated into the decision-making process. It is a dynamic process that attempts to identify, record, analyze and synthesize ideas, concerns, needs and values before recommendations are given to government decision makers.

PUMPING INTERFERENCE — The condition occurring when a pumping well lowers the water level in a neighbouring well.

PUMPING TEST — A test conducted by pumping a well to determine aquifer or well characteristics.

QUATERNARY — The period of geologic time (1.8 million years ago to present day) that follows the Tertiary. The Quaternary includes the Pleistocene and Recent Periods and is part of the Cenozoic Era.

RADIUS OF INFLUENCE — The radial distance from a pumping well to the point where there is no drawdown of the water table or piezometric surface. This point marks the edge of the cone of depression around the pumping well.

RECHARGE — The quantity of water that is added to a groundwater reservoir from areally distributed sources such as the direct infiltration of rainfall or leakage from an adjacent formation. [L] mm.

RECHARGE AREA (GROUND WATER) — An area where water infiltrates into the ground and joins the zone of saturation. In the recharge area, there is a downward component of hydraulic head.

REGIONAL WATER TABLE — See Water Table.

RENEWABLE WATER RESOURCES — Natural resources that, after exploitation, can return to their previous stock levels by natural processes of growth or replenishment.

RETURN FLOW The amount of water that reaches a surface or ground water source after it has been released from the point of use and thus becomes available for further reuse. Also called return water.

RUN-IN — Surface water that moves directly to ground water through vertical channels in the soil and/or rock layer.

RUNOFF — The portion of precipitation or irrigation water that moves across land as surface flow and enters streams or other surface receiving waters. Runoff occurs when the precipitation rate exceeds the infiltration rate.

RUNOFF COEFFICIENT — The estimated **Surface**

Run-off expressed as a fraction of the **Effective Rainfall**. [D].

SABKHA — Sabkha is an Arabic name for a salt-flat ordinarily found nearby sand dunes. These relatively flat and very saline areas of sand or silt form just above the water-table where the sand is cemented together by evaporite salts from seasonal ponds.

SAFE YIELD — The amount of ground water that can be withdrawn continually from an aquifer in an economical and legal manner without having any adverse effect on the ground water resource or on the surrounding environment.

SALINE GROUND WATER — Ground water consisting of or containing salt.

SALINISATION — The accumulation of soluble salts at the surface or at some point below the surface of the soil conditions to levels that have negative effects on plant growth and/or on soils. This occurs due to water evaporation leaving behind salts that were dissolved in water. Salinisation can be from capillary rise of saline groundwater or resulting from irrigation with saline water.

SALT WATER INTRUSION — Movement of salty or brackish ground water into wells and into aquifers previously occupied by fresh or less mineralized ground water either through upconing or sea water encroachment.

SANDSTONE — A sedimentary rock composed of mostly sand sized particles.

SANITARY SURFACE SEALS — A grouted annular space around the well casing which usually extends from the land surface to several metres deep. The sanitary well seal functions to prevent any contaminated surface and near surface water from seeping down the side of the well to the aquifer.

SATURATED ZONE — The subsurface zone in which all voids are ideally filled with water under pressure greater than atmospheric.

SEAWATER ENCROACHMENT — The lateral landward movement of sea water into wells and freshwater aquifers.

SEDIMENTARY ROCKS — Rocks formed from consolidation of loose sediments such as clay, silt, sand, and gravel.

SEEPAGE — The infiltration and percolation of surface water from overland flow, ditches, channels, ponds, lakes, streams, rivers, or other surface water bodies.

SHALE — A fine-grained sedimentary rock, formed by the consolidation of clay, silt, or mud. It is characterized by finely laminated structure and is sufficiently indurated so that it will not fall apart on wetting.

SPECIFIC CAPACITY — The rate of discharge of a water well per unit of drawdown. Specific capacity can be expressed as L/s/m of drawdown.

SPECIFIC CONDUCTANCE (GROUND WATER) — The ability of a water sample to conduct an electric current. Specific conductance is related to the concentration of dissolved solids in a water sample. A rapid determination of TDS of a water sample can be made by measuring the electrical conductance.

SPECIFIC PERMEABILITY — See **Permeability**.

SPECIFIC RETENTION. The volume of water that a unit volume of aquifer retains after gravity drainage. [D].

SPECIFIC YIELD — The amount of water in storage released from a column of aquifer of unit cross sectional area under unit decline of head. Expressed as a dimensionless proportion of the saturated mass of that aquifer unit. Effectively synonymous with **Coefficient of Storage** in an unconfined aquifer. Equivalent to **Effective Porosity**. [D].

SPRING — A surface water body created by the natural emergence of ground water to the Earth's surface.

Contact Spring A spring that usually occurs where a mass of permeable rock or unconsolidated materials overlie a mass of impermeable material.

Depression Spring A spring that occurs where the topography of the Earth's surface dips below the water table, thus forming marshes or small ponds.

Fault Spring A spring that originates where there is a fault in the rock layer.

STATIC WATER LEVEL — The level of water in a well that is not being influenced by ground water withdrawals. The distance to water in a well is measured with respect to some datum, usually the top of the well casing or ground level.

STORAGE COEFFICIENT — Volume of water stored or released from a column of aquifer with unit cross section under unit change in head.

STRATIGRAPHY — is that branch of geology concerned with understanding the geometrical relationships between sedimentary rocks and soils

STORATIVITY — See Coefficient of Storage.

SUBSURFACE DRAINAGE — See Drainage.

SURFACE DRAINAGE — See Drainage.

SURFACE WATER — The water from all sources that occurs on the Earth's surface either as diffused water or as water in natural channels, artificial channels, or other surface water bodies.

SURFICIAL DEPOSITS — Deposits overlying bedrock and consisting of soil, silt, sand, gravel and other unconsolidated materials.

SUSTAINED YIELD — Rate at which ground water can be withdrawn from an aquifer without long-term depletion of the supply.

TERTIARY — Geologic period of the Cenzoic Era and that period prior to the Quaternary.

THROUGHFLOW — See Interflow.

TOPOGRAPHY — The configuration of a surface including its relief and the position of its natural features.

TOTAL DISSOLVED SOLIDS (TDS) — Concentration of total dissolved solids (TDS) in ground water expressed in milligrams per litre (mg/L), is found by evaporating a measured volume of filtered sample to dryness and weighing this dry solid residue.

TRANSMISSIVITY — Rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity values can be expressed as square metres per day (m^2/day), or as square metres per second (m^2).

TRANSPIRATION — The process by which water absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface.

UNACCOUNTED FOR WATER — Discrepancy between water flows leaving the works and the total sum of all water received by the consumers; although mainly leakages, it includes significant metering errors and unknown/illegal diversions. Commonly used for the drinking water sector.

UNCONFINED AQUIFER — An aquifer in which the water table is free to fluctuate under atmospheric pressure.

UNCONSOLIDATED DEPOSITS — Deposits overlying bedrock and consisting of soil, silt, sand, gravel and other material which have either been formed in place or have been transported in from elsewhere.

UPCONING — Upward movement of salty or brackish ground water into wells and into aquifers previously occupied by fresh or less mineralized ground water.

UNSATURATED ZONE — The zone between the land surface and the water table. The pore spaces, interstices, contain water at less than atmospheric pressure, and also air and other gases. Perched ground water bodies (local saturated zones) may exist in the unsaturated zone.

VADOSE ZONE — A term sometimes used in place of unsaturated zone

VERTICAL ANISOTROPY — The difference between the vertical and horizontal flow properties of an aquifer. caused by layering.

VIRTUAL WATER — is the amount of food the country must import to compensate for the lack of water necessary for agricultural production

WADI — A channel, ravine or valley, dry, except in the rainy season.

WASTEWATER — Water which is of no further immediate value to the purpose for which it was used or in the pursuit of which it was produced because of its quality, quantity or time of occurrence. However, waste water from one user can be a potential supply to a user elsewhere.

WASTEWATER TREATMENT — Process to render waste water fit to meet applicable environmental standards or other quality norms for recycling or reuse. Three broad types of treatment are distinguished in the questionnaire: primary, secondary and tertiary

WATER BALANCE (HYDROLOGIC BUDGET) — A record of the outflow from, inflow to, and storage in a hydrologic unit like an aquifer, drainage basin etc.

WATERSHED — A catchment area for water that is bounded by the height of land and drains to a point on a stream or body of water, a watershed can be wholly contained within another watershed.

WATER CYCLE — See Hydrologic Cycle.

WATER LOGGING — State of land in which the water table is located at or near the surface resulting in yield of crops decline.

WATER MANAGEMENT — Planned development, distribution and use of water resources, in accordance with predetermined objectives and with respect to both quantity and quality of the water resources

WATER SUPPLY — Delivery of water to final users plus net abstraction of water for own final use

WATER QUALITY — The chemical, physical, biological, and radiological condition of a surface or ground water body.

WATER TABLE — See Ground Water Table.

WELL DEVELOPMENT — This operation helps make water enter the well more easily and can make the difference between a satisfactory and an unsatisfactory well. Different techniques for well development can be used, the aim is to remove the smaller sized particles from the aquifer surrounding the well screen and to provide a coarser filter zone around the screen. The smaller sized particles are drawn into the well screen and can then be removed by bailing or pumping.

WELLFIELD— A collection of wells or boreholes used for abstracting water

WELLHEAD PROTECTION — Protection of the recharge (or capture zone) area of a pumping well.

WELLHEAD PROTECTION AREA — A designated surface and subsurface area surrounding a well or well field that supplies a public water supply and through which contaminants or pollutants are likely to pass and eventually reach the aquifer that supplies the well or well field. The purpose of designating the area is to provide protection from the potential of contamination of the water supply. These areas are designated in accordance with laws, regulations, and plans that protect public drinking water supplies.

WELL INTERFERENCE — When the area of influence, or the cone of depression around a water well comes into contact with or overlaps that of a neighbouring well pumping from the same aquifer and thereby causes additional drawdown or drawdown interference in the wells.

WELL POINTS — Also referred to as sand points, gravel points,are used in shallow permeable unconfined (usually) aquifers generally less than 30 feet deep. Well points consist of a short length of screened pipe with a sharp point on the bottom end. As the pipe is driven into the ground, additional lengths of pipe are added to the top end. Sand points are also available with a check valve at the lower end to enable the pipe to be washed down in sand and fine gravel aquifers. Water can be pumped down the pipe and it passes out the check valve at the bottom and washes the sand up the hole to the ground surface.

WELL SEALS — Cover for the top of the well.

WELL SCREEN — A cylindrical filter used to prevent sediment from entering a water well. There are several types of well screens, which can be ordered in various slot widths, selected on the basis of the grain size of the aquifer material where the well screen is to be located. In very fine grained aquifers, a zone of fine gravel or coarse sand may be required to act as a filter between the screen and the aquifer.

WELL YIELD — The volume of water discharged from a well in litres per minute (L/min), litres per second (L/s) or cubic metres per day (m^3/day).

WETLAND— A land area that is inundated or saturated by surface and/or ground water with a frequency and duration sufficient to support an abundance of hydrophytic (water-loving) plants or other aquatic life that require permanently saturated or seasonally saturated soil conditions for growth and reproduction. Examples include swamps, marshes, bogs, sloughs, potholes, wet meadows, river overflow areas, mud flats, and natural ponds.

YIELD TEST— A short duration **Pumping Test** undertaken to establish a borehole's yield-drawdown characteristics

ZONE OF SATURATION — See Saturated Zone

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