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Global Overview of Saline Groundwater Occurrence and Genesis

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1 Introduction

1.1 Objective

The objective of this study is to broadly inform groundwater resources managers, engineers, policy-makers and politicians world-wide on the subject of managing saline groundwater with the aim to enhance their general understanding, promote early diagnosis of possible changes and widen their inspiration for selecting effective measures for intervention (as far as required).

This study has three focal areas:

1) *Geographic dimension*: Description and characterization and geographical delineation of global occurrence of saline groundwater
2) *Management dimension:* Description of risks and opportunities regarding brackish and saline groundwater and observed human responses (management and development practices)
3) *Global change dimension:* Analysis to what extent the presence and/or relevance of brackish and saline groundwater may change in response to global change processes such as climate change, ever-increasing groundwater abstraction and modified land use practices.

1.2 Study Output

The study's output consists of documentation on saline groundwater as it is observed and managed in different parts of the world. At this point it is important to note that in this study saline groundwater also comprises brackish groundwater and brines. The documentation includes:

- information on the origin and geographical distribution of saline groundwater in the world
- on factors that could motivate interventions for their control, use or removal/mitigation and on approaches and experiences with such interventions as observed in different parts of the world.

This study's output is presented in different forms:

- Hardcopy technical report with attached hardcopy map (this report)
- Web-version of a worldwide map showing saline groundwater occurrences and their genesis at shallow and intermediate depths published in IGRAC Global Groundwater Information System (see section 1.3)
- Hardcopy version of the worldwide map showing saline groundwater occurrences at shallow and intermediate depths to be published in the WHYMAP framework in near future
- Scientific article to be submitted in near future.

1.3 Background on IGRAC

The International Groundwater Resources Assessment Centre (IGRAC) - an initiative of UNESCO and WMO - was launched at the "Fifth International Conference on Hydrology" in February 1999. The centre is hosted at the DELTARES office in Utrecht, The Netherlands. For the initial years, it is financially supported by the Dutch inter-ministerial bureau 'Partners for Water'. IGRAC operates under the auspices of WMO and UNESCO (as UNESCO Institute - Category II).

An important part of the services of IGRAC to the world community is making information on the globe's groundwater available through IGRAC's website (www.igrac.net). On this website, three main technical entries have been developed:

(1) *Global Groundwater Information System (GGIS)*: envisaged as a platform for exchanging and disseminating area-specific information on groundwater on a global scale.
(2) *Guidelines and Protocols*: intended to stimulate and improve observation of groundwater parameters and variables, mainly through methodological assistance.

(3) *Special projects*: providing information on a variety of projects IGRAC is involved in.

The Global Groundwater Information System (GGIS) was designed as a modular system, with the following main structure:

(a) *Global Overview*: country- and region-based modules, providing overviews based on a standard set of parameters/indicators.
(b) *Detailed Information*: complementary to Global Overview by zooming in on special regions/areas and/or themes, thus providing more detail.
(c) *Services and Enabling Environment*: meta-information module and collaborative environment (including digital workspace, audio-video conferencing and discussion forum).

The study resorts under (3). Activities already carried out under this module are Arsenic worldwide, Fluoride worldwide, and the December 2004 tsunami (all parked under ‘Special projects’). Ongoing in this category are projects on ‘Change in groundwater’, ‘Transboundary aquifers’ and ‘Artificial Recharge’.

1.4 Report Overview

Chapter 2 gives the definition of saline groundwater used in this study. It describes various genetic origins of saline groundwater and the salinity dynamics. Chapter 3 gives the methodological framework for collecting, analyzing and processing the data and proxy information to develop a worldwide overview of saline groundwater occurrences. Results from this methodology are presented in this chapter, in annex 1 (map) and annex 2 (table wise description of saline groundwater occurrences per global groundwater region. Chapter 4 discusses the role saline groundwater plays in human society and in natural processes. Chapter 5 gives an overview of techniques, actions and measures that people undertake worldwide to mitigate remediate and adapt to groundwater salinity. Chapter 6 gives an analysis of the worldwide scope and severity of groundwater salinity and concluding remarks.

2 Background information on saline groundwater

2.1 What is saline groundwater?

The contents of dissolved solids in groundwater vary highly from one location to another on earth, both in terms of specific constituents (e.g. halite, anhydrite, carbonates, gypsum, fluoride-salts, and sulphate-salts) and regarding the concentration level. The latter, often called salinity level is a convenient macro-parameter for a first general characterization of water quality. It is usually expressed as *Total Dissolved Solids* (TDS) – i.e. milligrams dissolved solids per litre of water, but the use of proxies such as the *Chloride Content* (mg/l) or the *Electrical Conductivity* (EC, in µS/cm) is widespread as well.

In practice, water often is classified into a number of discrete salinity classes. Number and names of classes, parameters to which class limits are linked (Total Dissolved Solids, chloride content, EC) and numerical values of class limits vary among published classifications. In this study the simple classification presented by Freeze and Cherry (1979) is used which is based on TDS levels. It recognizes only four classes and the names of these classes are very widely used and well understandable for the public (see Table 2-1).

Table 2-1: Water salinity classification

Class name	**Class limits (TDS range, in mg/l)**
Fresh water	0 - 1,000
Brackish water	1,000 - 10,000
Saline water	10,000 - 100,000
Brine	> 100,000

(After Freeze and Cherry, 1979)

Where salinity levels are specified in terms of chloride content (mg Cl/l) or EC (µS/cm), approximate conversions to TDS (mg/l) can be made by using the respective multipliers of 1.8 and 0.7. In this inventory the lower limit of 1,000 mg/l, TDS is used. Thus, when talking in this report about saline groundwater, this tacitly includes brackish groundwater and brines as well.

2.2 Genetic background of saline groundwater

In general, fresh groundwater is particularly found in those parts of the subsurface that are most actively involved in the water cycle, the domain of so-called 'meteoric water'. Consequently, fresh groundwater is more likely present in the shallower domains of the sequence of geological layers in which groundwater is stored. Based on this rationale, fresh groundwater is often comparatively young and tends to be actively recharged. In contrast, a large part of all saline groundwater on earth – but certainly not all of it – is present in a more or less stagnant condition at greater depths and may have been there already for many thousands or even millions of years. Continuous dissolution over geological times of the reservoirs containing this groundwater may have enriched the mineral content in the groundwater. So groundwater salinity tends to increase with increasing depth.

Genetically, most saline groundwater bodies are to one of the following categories:

- Saline groundwater of marine origin
- Saline groundwater of terrestrial origin (natural)
- Saline groundwater of terrestrial origin (anthropogenic)
- Saline groundwater of mixed origin

2.3 Saline groundwater of marine origin

(A1) Connate saline groundwater

This is typical for sedimentary formations of marine origin: seawater was deposited together with the rock matrix and still is present in the interstices, unless it has been flushed afterwards. Under natural boundary conditions, migration of connate saline groundwater tends to be extremely slow.

(A2) Saline groundwater originating from marine transgressions

Throughout geological history, the sea level tends to change over time. Consequently, it is common that coastal lowlands became flooded by the sea during marine transgression periods. During the transgression period, seawater flows downwards because of density differences and may have turned originally fresh coastal aquifers into saline groundwater reservoirs. This process is relatively fast. Within hundreds of years, aquifers of hundreds of meter thickness may turn saline due to this process.

(A3) Saline groundwater originating from incidental flooding by seawater

A similar mechanism of salinization may occur at a much smaller time basis. When sea levels are exceptionally high, e.g. during a tsunami, or when coastal defence systems fail during high tides, low-lying coastal plains may become regularly flooded by seawater. Although the period of flooding is much smaller than in the case of a marine transgression, large extents of coastal aquifers nevertheless may become salinized due to the infiltration of seawater ponded on land surface. The effect is particulate in and mostly limited to the shallow (first meters) domains of these aquifers. Temporal submersion of unprotected wellheads during the flooding may lead to introduction of saline water to greater aquifers depths via the well screens.

(A4) Groundwater originating from laterally intruded seawater.

This genesis occurs in coastal zones because of interaction between the seas and hydraulically connected coastal aquifers. In a dynamic equilibrium, this results in a natural landward thinning 'saltwater wedge' overlain by fresh groundwater discharging into the sea (Bear et al., 1999). Lateral seawater intrusion in coastal areas may be enhanced by surface water bodies connected to the sea, such as estuaries and rivers (greatly increasing the coastline length) if conditions allow seawater to travel inland through these bodies. When the shallow fresh groundwater resources are abstracted for human productive use and when land use changes decrease groundwater replenishment the shallow fresh groundwater head decreases. This can cause up-coning of deeper often more saline groundwater and an inland movement of the fresh/saline groundwater interface. Also decreased estuarine river discharge because of upstream water allocation may increase seawater intrusion. This anthropogenic induced intrusion is a can be a relatively fast process depending on the hydraulic pressures changes and the transmissivity of the coastal aquifers[1].

(A5) Groundwater enriched in mineral content by seawater sprays

The lower air in coastal zones may be rich in salt particles, originating from the sea. These salt particles will be absorbed by rains and be incorporated in groundwater recharge water, thus contributing to groundwater salinization.

[1] In literature it is common practice to use the term 'seawater intrusion' for what here is called 'lateral seawater intrusion' (A-4), in spite of the fact that the categories A2, A3 and A5 are also related to intruding seawater (intruding from above).

Table 2-2: Genetic categories of saline groundwater

Main class of origin	*Genetic category or salinization mechanism*	*Typical environment at the time of origin*
A0 Marine origin	A1. Connate saline water	Coastal zone (off-shore)
	A2. Intruded by marine transgression	Coastal zone (off-shore)
	A3. Intruded by recent incidental flooding by the sea	Coastal zone (on-shore)
	A4. Laterally intruded seawater	Coastal zone (on-shore)
	A5. Intruded seawater sprays (aerosols)	Coastal zone (on-shore)
	A6. Mixture of A2 (marine transgression) and A3 (recent incidental flooding by sea)	Coastal zone (on and off-shore)
	A7. A6. Mixture of A1 (connate water), A2 (marine transgression) and A3 (recent incidental flooding by sea)	Coastal zone (on and off-shore)
B0 Terrestrial origin - natural	B1. Produced by evaporation (concentration)	Shallow water-table zones in arid climates
	B2. Produced by dissolution of subsurface salts	Zones of salt tectonics or regional halite or other dissolvable formations
	B3. Produced by salt filtering membrane effects	At depth in thick sedimentary basins containing semi-permeable layers
	B4. Emanated juvenile water and other products of igneous activity	Regions of igneous activity
	B5. Mixture of B1 (evaporation) and B2 (dissolution)	Shallow water-table zones in arid climates and aquifers containing dissolvable formations
C0 Terrestrial origin - anthropogenic	C1. Produced by irrigation (input of concentrated residual water)	Arid and semi-arid zones; shallow depths
	C2. Anthropogenically polluted groundwater	Anywhere on earth, particularly in modern consumptive societies
D0 Mixed origin	D0 Saline groundwater produced by mixing an A-, B- or C-class mineralized groundwater with fresh water or with another type of saline groundwater.	Anywhere on earth; hydraulic gradients facilitate the mixing processes

2.4 Saline groundwater of terrestrial origin – natural

(B1) Groundwater enriched in mineral content by evaporation at or near land surface.

This origin of saline groundwater is linked to shallow water table conditions, and develops when climatic conditions favour evaporation (or evapotranspiration through phreatophyts) while flushing of accumulated salts is absent or only weak (Yechieli and Wood, 2002). Such conditions prevail on the so-called *chotts*, *sebkhas, salinas, salars* or *playas* (names of saline lakes in closed basins in various languages and geographical areas in arid and semi-arid regions). It is assumed that the high lake salinity spreads in the underlying groundwater to some depths and to some distances. Often a salt crust is formed at the lake bottom during dry periods.

(B2) Groundwater enriched in mineral content by dissolution of naturally occurring soluble minerals underground.

Groundwater may become saline by dissolving salts from evaporate formations (halites) or carbonates layers, when flowing through or along such subsurface bodies. Even when flowing through ‘ordinary’ aquifers (of which only a limited fraction consists of easily dissolvable materials) groundwater may become brackish to saline in downward direction, if time and other conditions favour dissolution of salts from the aquifer matrix (not uncommon in arid regions).

(B3) Saline groundwater produced as a result of membrane effects

Layers of clay or shale may be compacted that much in deep sedimentary basins that they become effective salt filtering membranes. Groundwater is percolating through such layers but the dissolved larger ions are not permitted to pass, which leads to building up high groundwater salinity (even brines) near the inflow side of the membrane. This fractionation process often causes brines constituting of calcium and chlorides (Hem, 1970). The process is called salt filtering, ultra-filtration or hyper-filtration.

(B4) Saline groundwater of geothermal origin

In addition to the meteoric and connate waters that form the point of departure of the previous genetic types of saline water, one may encounter highly mineralized water that is produced as a side product of igneous activity. Since it has not been part of the hydrological cycle yet, it is called 'juvenile water'. This process is rare but may be observed in regions of prominent igneous activity.

Highly pressurized and high temperature groundwater that is present (mostly at greater depths) within areas with high igneous activity has a high dissolving capacity. This groundwater may be enriched in dissolved salts resulting in so-called thermo-mineral waters. In addition, cases of seawater flowing into these volcanic and igneous systems are known. Hydrothermal groundwater systems may transport this highly salinized groundwater to shallower depths and even create localized hot and salty springs at the surface.

2.5 Saline groundwater of terrestrial origin – anthropogenic

(C1) *Groundwater enriched in mineral content by irrigation.*

Irrigation is augmenting water required for optimal crop evapotranspiration. Water vapour leaving the crops during this process is almost without dissolved solids, thus much less mineralized than the irrigation water supplied. Large-scale irrigation may also lead to shallow groundwater tables (water-logging) and non-beneficial evaporation directly from that water table. Consequently, a residue of relatively mineralized water is left in the soil. From there it may adsorb to the soil matrix (soil salinity), drain to the surface water system or percolate below the root zone. It may reach an aquifer and contribute to a progressive increase in salinity of its groundwater. In addition, irrigation by means of application of brackish water from some source (for example waste water) may create salinization of the underlying groundwater system. It is assumed that the groundwater salinization because of irrigation is restricted to the first meters to tens of meters below the groundwater table.

(C2) *Groundwater enriched in mineral content by anthropogenic pollution a*nthropogenic pollutants may enter the groundwater system and contribute to increased salinity of groundwater. Typical examples of such anthropogenic pollutants are road salt (applied in winter), fertilizers, domestic, industrial and agricultural effluents, spilled oil and gas field brines and brines from desalinisation plants. Groundwater salinization effects of these processes will be rather localized.

(D0) *Saline groundwater of mixed origin*

This category refers to mixes between different types of saline water as described above or to water resulting from one or more of these categories mixed with fresh groundwater. Brackish transitional zones between saline groundwater wedges and overlying fresh groundwater bodies are a typical example.

Given the characteristic large residence times of groundwater, the time dimension should not be overlooked when defining the origin of saline groundwater. E.g., saline groundwater may have originated in past geological periods when prevailing climatic or water-table conditions were different from what they are nowadays. Furthermore, bodies of saline groundwater may have migrated since they were formed, as is the case as is the case with a hypersaline groundwater body west of the Dead Sea (see region 1; Levant and Arabian platform in Annex 2).

The genetic categories B3 and B4 are associated mainly with geological processes at great depth. However, groundwater flow systems may be such that deep groundwater and the related salts are transported to shallower depths as a result of land subsidence, polder drainage and groundwater exploration.

In some regions, the groundwater salinity origins appear simultaneously. In low-lying coastal zones and delta areas, the groundwater salinity is often caused by past marine transgressions and recent incidental flooding (A6). In some cases, also connate saline groundwater adds up to the total observed groundwater salinity (A7). Evaporation induced salinization is significantly exacerbated when the evaporating groundwater is enriched in dissolved salts picked up along the flow line in the aquifers (B5).

2.6 Regarding saline groundwater dynamics

The geographic distribution of fresh, brackish and saline groundwater is not fixed in time, but subject to change. Some of the observed changes are taking place very slowly and are only significant at a geological time scale. Others, on the other hand, may proceed more quickly. The formation of saline groundwater and the migration and/or mixing of these categories of groundwater are put into motion by certain drivers. These drivers can be natural processes such as geological processes, meteorological processes, climate change, tsunamis, earth quakes, consolidation of compressible sediments; but also anthropogenic factors, such as drainage, irrigation, groundwater pumping, waste or wastewater disposal, etc. The nest sections discuss how these drivers affect the dynamics of groundwater salinity.

2.7 Natural drivers affecting groundwater salinity

- *Deposition of marine sediments*: During this geological process, seawater fills the voids of the sediments (connate water). Often it remains trapped inside the sediment matrix for a very long period, even if the marine environment has retreated.
- *Sea level variations:* Rising sea levels may cause flooding of coastal land by seawater, either for a long period (marine transgressions) or a short one (storm flood events, tsunamis). In addition, they tend to boost lateral seawater intrusion into coastal aquifers that are hydraulically connected to the sea. Reduced sea levels, like those prevailing on a global scale during the Pleistocene, create conditions for intensified flushing of coastal saline groundwater domains and for wider development of coastal karst circuits.
- *Meteorological processes and the hydrological cycle:* On a worldwide scale, evaporation contributes steadily to the formation of brackish and saline groundwater, in particular by producing evaporates. Rainfall, on the other hand, tends to have an opposite effect and activates those parts of the hydrological cycle that may flush and refresh bodies of saline groundwater.
- *Climate change:* This phenomenon has a more direct impact by modifying meteorological variables and an indirect impact by change in sea level. Climate change anticipated for the current century (admittedly, not an entirely 'natural' phenomenon) would cause a global rise in atmospheric temperatures and rising sea levels. This will intensify the risks of seawater intrusion and especially in areas where in addition the rainfall becomes less, salinity levels of groundwater may increase as well by higher mineralization of recharge water, by intensified formation of evaporate products, by less intensive natural flushing and by stronger anthropogenic pressures (irrigation, waste and waste water disposal, groundwater abstraction, etc.).

2.8 Anthropogenic drivers affecting groundwater salinity

- *Coastal protection, land reclamation and drainage*. These human activities have a strong impact on local and regional hydrological conditions. On the one hand, they may reduce the encroachment of seawater into the aquifers. However, if drainage results in declined groundwater levels, then this may change the groundwater regimes in the sense that connate saline groundwater migrates into formerly fresh aquifers and lateral intrusion of seawater becomes more intensive.

- *Groundwater abstraction* modifies the local subsurface hydrodynamic pressure field. If saline groundwater is part of the subsurface system, then they tend to become mobilized because of pumping and invade into relatively fresh zones.
- *Irrigation* tends to increase gradually the salinity levels in soil water, surface water systems and/or aquifers. This is because the crops transpire almost pure water, which means that applied irrigation leaves a residue of dissolved substances. The effects are most pronounced under arid conditions.
- *Intentional and unintentional disposal of waste or waste water:* Intentional disposal includes the subsurface injection of saline water as applied in the oil industry and the operation waste disposal sites, both of which potentially may turn fresh groundwater saline. Non-intended disposal of waste or wastewater may possibly contribute to groundwater salinity: domestic and industrial pollution, use of road salt in winter (for de-icing purposes).

Proper identification and knowledge of the conditions and mechanisms, combined with access to predictive tools (models) allow groundwater resources managers to design and implement measures that control the patterns of saline groundwater to a certain extent. Most professional activities related to saline groundwater have this purpose.

3 Methodological framework for global saline groundwater description

3.1 Selecting a reference system for the geographical dimension of saline groundwater

Describing the geographical distribution of saline and brackish groundwater on a global scale requires a reference system that enables quick orientation. It preferably bears a relation to physical units relevant for understanding the distribution. As such, the system of Global Groundwater Regions, developed by IGRAC, is used. In cases where more differentiation within these regions is needed, reference is made to individual countries or zones identifiable by a geographical name.

3.2 IGRAC's Global Groundwater Regions

IGRAC's system of *Global Groundwater Regions* attempts - by a macroscopic subdivision of the earth's land surface - to contribute to a better perception and understanding of the global pattern of predominant groundwater conditions. The basic underlying assumption is that large-sized territories (regions) can be delineated that have a characteristic overall groundwater setting contrasting with that of neighbouring regions. Thus, they can be considered as distinct units. The names given to these global groundwater regions have been linked to current geographical names, in order to strengthen the notion where they are located. Because it is intended that people will memorize the regions, their number has been kept low (36 global groundwater regions). This however, puts limitations to the degree of uniformity of groundwater conditions within one single region.

The 36 Global Groundwater Regions used as a geographic reference in this report are shown in Figure 3.1 and listed in Table 3-1. A brief description of each of them is included in Appendix 2. Four distinct types of Global Groundwater Regions can be distinguished:

- *Basement regions*: predominance of basement outcropping at the surface or located at relatively shallow depths, hence relatively poor groundwater conditions and limited groundwater storage (red colours in Figure 3.1).
- *Sedimentary Basement regions*: predominance of sedimentary basins, offering good conditions for groundwater flow and storage. These regions contain the world's most prospective groundwater resources (yellow colours in Figure 3.1).
- *High-relief Folded Mountain regions*: regions dominated by folded mountains producing high topographic relief. Groundwater occurrence in such regions usually is fragmented pockets, with high lateral variations over relatively small horizontal distances (green colours in Figure 3.1).
- *Volcanic regions*: regions where volcanic rocks and volcanism are strongly conditioning groundwater conditions (blue colours in Figure 3.1).

Table 3-1: Global Groundwater Regions

No	Name	Type of region	Approximate location
1	Western mountain belt of North and Central America	High-relief Folded Mountain region	North & Central America
2	Central plains of North and Central America	Sedimentary Basin region	North & Central America
3	Canadian shield	Basement region	North America
4	Appalachian highlands	High-relief Folded Mountain region	North America
5	Caribbean islands and coastal plains of North and Central America	Sedimentary Basin region	North & Central America
6	Andean belt	High-relief Folded Mountain region	South America
7	Lowlands of South America	Sedimentary Basin region	South America
8	Guyana shield	Basement region	South America
9	Brazilian shield and associated basins	Basement region	South America
10	Baltic and Celtic shield	Basement region	Europe
11	Lowlands of Europe	Sedimentary Basin region	Europe
12	Mountains of Central and Southern Europe	High-relief Folded Mountain region	Europe
13	Atlas mountains	High-relief Folded Mountain region	Africa
14	Saharan basins	Sedimentary Basin region	Africa
15	West African basements	Basement region	Africa
16	Sub-Saharan basins	Sedimentary Basin region	Africa
17	East African basement and Madagascar	Basement region	Africa
18	Volcanics of East Africa	Volcanic region	Africa
19	Horn of Africa basins	Sedimentary Basin region	Africa
20	West Siberian platform	Sedimentary Basin region	Asia
21	Central Siberian plateau	Basement region	Asia
22	East Siberian highlands	High-relief Folded Mountain region	Asia
23	North-Western Pacific margin	Volcanic region	Asia
24	Mountain belt of Central and Eastern Asia	High-relief Folded Mountain region	Asia
25	Basins of West and Central Asia	Sedimentary Basin region	Asia
26	Mountain belt of West Asia	High-relief Folded Mountain region	Asia
27	Himalayas and associated highlands	High-relief Folded Mountain region	Asia
28	Plains of Eastern China	Sedimentary Basin region	Asia
29	Indo-Gangetic-Bramaputra plain	Sedimentary Basin region	Asia
30	Nubian and Arabian shields	Basement region	Asia/Northern Africa
31	Levant and Arabian platform	Sedimentary Basin region	Asia
32	Peninsular India and Sri Lanka	Basement region	Asia
33	Peninsulas and Islands of S-E Asia	Volcanic region	Asia
34	Western Australia	Basement region	Oceania
35	Eastern Australia	Sedimentary Basin region	Oceania
36	Islands of the Pacific	Volcanic region	Oceania

3.3 Approach to collecting information on saline groundwater

There are numerous large, medium sized and small bodies of saline groundwater in the world; similarly, there are also numerous sources of information on these groundwater bodies. The following criteria were adopted for this global inventory:

(a) *Depth of occurrence:*

For practical reasons, the inventory of the occurrence of brackish and saline groundwater is limited to the subsurface domains currently considered relevant for the exploitation and regular management of groundwater. This means that the collected information does not go beyond some 200 to 500 m below ground surface. The corresponding target depth zone is referred to in this report as “shallow and intermediate depths”.

Some of the saline groundwater bodies found only have a limited depth horizon. For example, the depth horizon of groundwater salinization due to irrigation practices normally does not go beyond meters. Consequently, only part of the groundwater column up to 500 meters depth is salinized in such a location while the rest remains fresh. Still, in this inventory this area is denoted to have saline groundwater.

(b) *Size of the saline groundwater body*

No general criteria have been developed for a minimum size of groundwater bodies to be considered. Nevertheless, no attention has been paid to relatively small bodies of saline groundwater, as they are irrelevant on the global scale and would require excessive time for their inclusion in the inventory. How to interpret “relatively small” depends on local conditions, but single groundwater bodies containing less than one billion cubic metres of saline water in storage are unlikely to be included in the inventory, unless they are considered very significant for one reason or another, and/or form part of a pattern that covers significant area or length. The occurrence of hydrothermal springs is an example of this. Though the surfacing springs themselves are localized with limited geographical extent, they may represent larger hydrothermal groundwater systems.

(c) *Number and type of information sources explored*

It is assumed that providing such description on hard data would be an infeasible endeavour at this stage. Data on groundwater quality like TDS is non-existent for large areas in the world and when they do exist, it may not be easily accessible and non-uniform. It was therefore decided to make a global description of occurrences based on information and knowledge instead of on hard data (groundwater quality measurements). Hence, this description is based on documented cases of saline groundwater occurrences combined with various kinds of proxy information. The main information sources used were:

- Working papers and Project Reports from relevant organisations on this subject
- Proceedings of professional meetings relevant for the subject (in particular SWIM).
- Papers in professional journals relevant for the subject
- Websites with relevant information
- Proxy information like maps with distributions of geological, geographical, soil, land use, irrigation, aridity, elevation data, and storm and flood frequency data.

(d) *Confirmed versus inferred*

In many cases, documentation on measured occurrences of saline groundwater only represents geographical areas of limited spatial extent. Often the size of a scientific case study or project area is much smaller than the minimal size of saline groundwater bodies considered under topic b. Therefore, proxy information and expert judgement is used to extrapolate the documented occurrences into larger areas where a high probability of groundwater salinity is assumed.

3.4 Processing, analysing and presenting information on saline groundwater

Most of the information obtained in this project is tailored for presentation in the Global Groundwater Information System that is accessible on IGRAC's portal. The following outputs are considered

(a) *Global map*
A global map with saline groundwater occurrences is constructed. The map gives insight in the horizontal geographical extent and on the (probable) genetic origin of the saline groundwater as explained in Section 2.2 and in Table 2-1. Annex 1 contains the global map (size A2, scale 1:40.000.000). The map is also accessible on IGRAC's web-portal. One can click on the various occurrences of saline groundwater. This automatically prompts the tabular saline groundwater description of the Global Groundwater Region in which the particular occurrence is located.

(b) *Global groundwater region tabular saline groundwater description*
For each Global Groundwater Region, a saline groundwater description is made. The description contains the following aspects:
- Countries included
- Generalized hydrogeological setting
- Adequacy of information accessed on saline groundwater
- Main occurrences, origin and dimensions of shallow saline groundwater
- Current or potential threats of saline groundwater to the interests of society or ecosystems
- Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems
- Human responses to threats and or opportunities(management)
- Impact of expected or observed global change
- Selected references.

The tabular descriptions are given in annex 2.

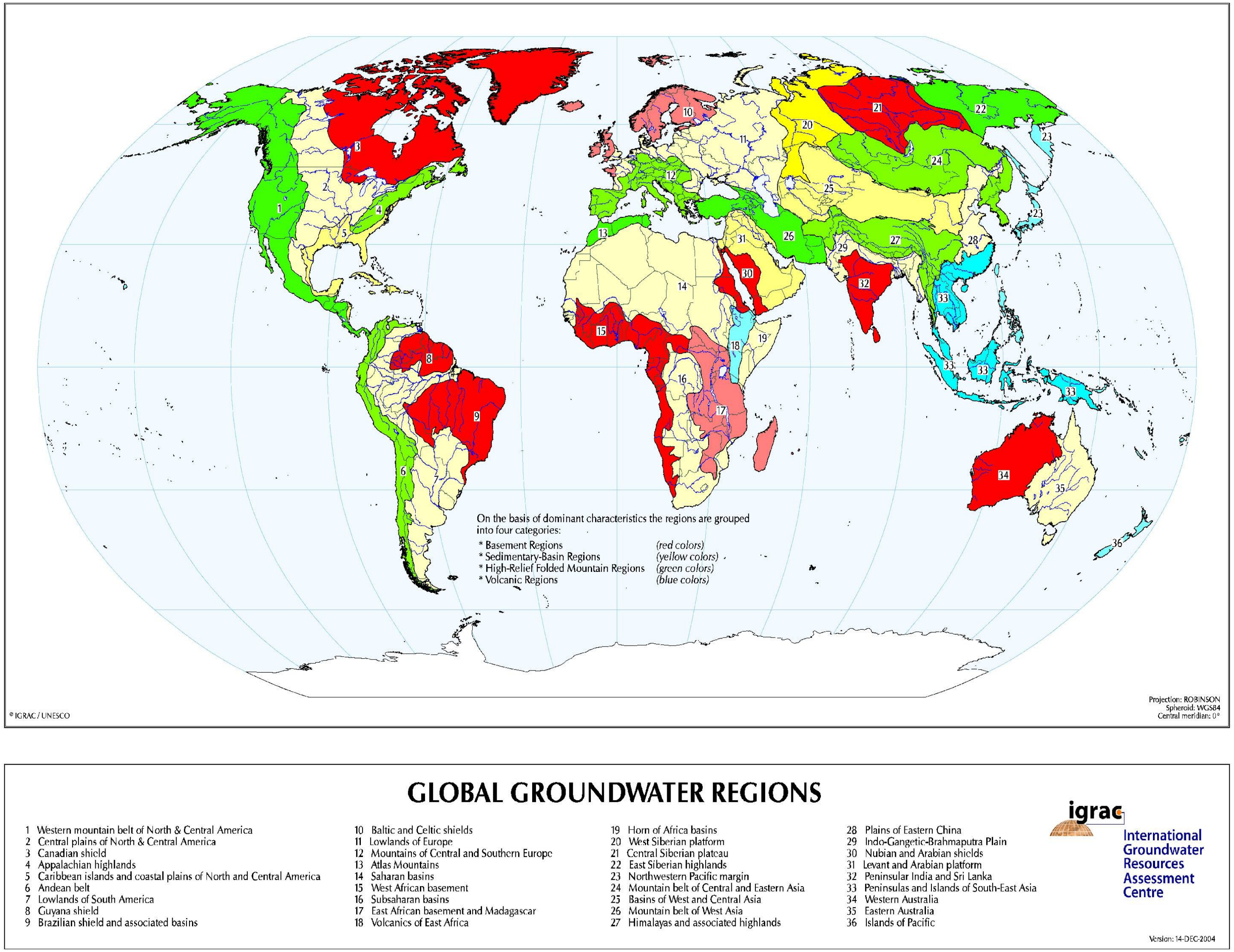

Figure 3.1: Global Groundwater Regions

4 Role and significance of saline groundwater

Groundwater is abstracted and used because of its consumptive value (drinking and food preparation) and productive value (irrigation water, industrial processes). Also in-situ values of groundwater (baseflow to rivers, feeding to ecosystems, ecological habitat, and hydraulic buffer to seawater ingress) are increasingly being acknowledged. For many of the activities and processes where groundwater is used certain groundwater quality levels are desired or essential. The next section gives an overview on how saline groundwater may affect these activities and processes and may form risks. However, saline groundwater may also provide opportunities and this is discussed in the second section in this chapter.

4.1 Saline groundwater risks

- *Drinking water for humans:* Groundwater is often used as a resource for drinking water. Currently, proof of negative health effects associated with the ingestion of high TDS water is not evident (WHO, 2006). Hence, the World Health Organisation has not defined a health-based drinking water quality guideline value for TDS (earlier WHO had a highest desirable TDS guideline of 500 mg/l and a maximally permissible TDS guideline of 1500 mg/l). There are however, some studies that suggest that continuous consumption of saline water may lead to human conditions of hypertension like found by Khan et al. (2008). Moreover, the presence of high levels of TDS in drinking-water (greater than 1200 mg/litre) is assumed to be taste-wise objectionable to consumers. The palatability of water with a TDS level of less than 600 mg/litre is generally considered to be good. Water with very low concentrations of TDS may also be unacceptable because of its flat, insipid taste. Despite that, there is no WHO health-based level drinking water quality value for TDS; such values do exists for individual chemical components like fluoride that contribute to salinity.
- *Plant growth:* The presence of salt in the soil moisture causes plants to exert more energy extracting water from the soil. The main point is that excess salinity in soil water can decrease the plant's water availability and cause plant stress. The amount of plant stress is dependent on soil type, plant species and salinity level. Toxicity problems may occur if certain constituents (ions) in the soil or in the water are taken up by the plant and accumulate to concentrations high enough to cause crop damage and limit plant growth. Ions of primary concern are chloride, sodium and boron. Although toxicity problems may occur even when these ions are in low concentrations, toxicity often accompanies and complicates a salinity or water infiltration problem (Ayers and Westcot, 1985).
- *Soil properties:* Soil water salinity affects the soil properties by causing fine particles to flocculate into aggregates. This is beneficial in terms of soil aeration, root penetration, and root growth. Sodium has the opposite effect of salinity on soils. High sodium concentrations disrupt the forces that bind clay particles together. When this separation occurs, the clay particles expand, causing swelling and soil dispersion. Soil dispersion causes clay particles to plug soil pores, resulting often in reduced soil permeability and consequent reduced infiltration capacity (Rhoades et al., 1992).
- *Crop yield and agricultural production:* The above described combined effects of soil and water salinization may reduce crop yields, limit the choice of crops to be grown in a certain area and may make land semi-permanently unsuitable for further agricultural purposes. Various researchers have studied the relationships between yield potential and salinity levels. Grattan (2002) provides a list of salinity tolerance coefficients for various crops.
- *Watering of livestock:* Watering of livestock with high salt content may cause physiological upset or even death in livestock (Ayers and Westcot, 1985). The main reported effect is loss of appetite, which is usually caused by a water imbalance rather than related to any specific ion. The most common exception is water containing a high level of magnesium which is known to cause scouring and diarrhoea. The National Academy of Sciences (1974) established that,

from a salinity standpoint, livestock drinking water with an electrical conductivity less than 5000 µS/cm should be satisfactory under almost any circumstances.

- *Infrastructure:* Groundwater salinity may reduce the life of domestic, agricultural and industrial equipment and increases maintenance costs. The salinity may cause corrosion of metals (e.g. pipes water & gas distribution, industrial installations) and concrete (building foundations, canal lining). Also scaling (crust formation) due to the precipitation of dissolved salt when materials are in contact with highly salinized groundwater may be a serious problem. Salinity increases the "hardness" of water, which may necessitate the use of more soap and detergents or water softeners installed and maintained. High groundwater salinity may increase the need for chemicals or other means of water treatment.
- *Ecosystems:* Various types of aquatic ecosystems that are groundwater-dependent existing in lakes, wetlands and rivers are found in large numbers. In addition, various types of terrestrial ecosystems exist with vegetation that is depending on shallow groundwater levels. Discharge of saline groundwater into these aquatic and terrestrial ecological systems often leads to a general biodiversity loss and a change into more salt-tolerant type of biota (Williams 1999).
- *Costs of groundwater salinization:* Groundwater salinization does not go without associated costs. Direct financial costs for groundwater users or beneficiaries may rise since the drinking water price may go up in case of high TDS levels necessitating additional purification treatment. Farmers may experience decreased agricultural profits since crop yields may be suboptimal and parts of the land need to be abandoned in case of high soil and water salinity. Industrial producers may face increased production and maintenance cost when groundwater with high TDS is used in their processes.

On a larger scale, groundwater salinization may cause significant societal economic costs. Maintenance of corroded roads, sewage works and building foundations make huge cuts in budget of governments. Large-scale salinization in the agricultural sector may result in various kinds very costly interrelated socio-economic problems like loss of livelihood, unemployment, migration and food insecurity. Some studies quantified the costs of land and water salinization in monetary terms. In Australia, the estimated annual costs of salinization are substantial: $130 million in agricultural costs, $100 million in infrastructure costs, and $40 million in environmental costs (MDBC, 2007). The Indus Basin Irrigation System enormously boosted the agricultural production in Pakistan. However, salinization caused by water-logging and by application of poor quality groundwater declined the crop yields increasingly over the last decades. Current estimates of losses of land and decreased yields are about $240 of revenue per hectare per year (Aslam and Prathapar, 2006).

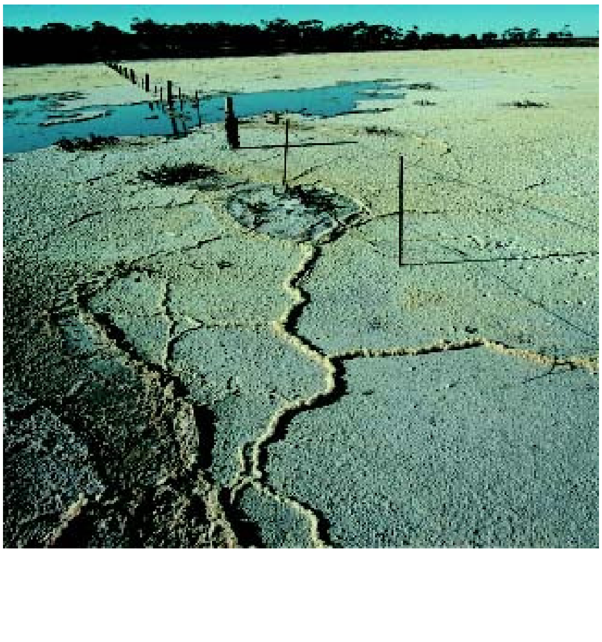

Figure 4.1: Dryland salinity in Murray Darling Basin, photo by MDBC

On top of these costs are the non-market costs of salinization, such as the visual effects, the ecological damage done to environments, and in some instances, the total loss of wetlands.

4.2 Saline groundwater opportunities

However, other (more positive) views on saline groundwater can be observed as well:

- *Halophile ecosystems:* Saline groundwater may have a role in maintaining habitats for halophiles, aerobic microorganisms that live and grow in high saline environments. These microorganisms use osmotic pressure and chemical substances like sugars, alcohols, amino acids to help control the amount of salt inside the cell. The saline content in halophilic environments is usually 10 times the salt content of normal ocean water. Some known examples of halophilic environments are the Great Salt Lake in Utah, Owens Lake in California, Lake Natron in Tanzania and the Dead Sea in the Middle East.

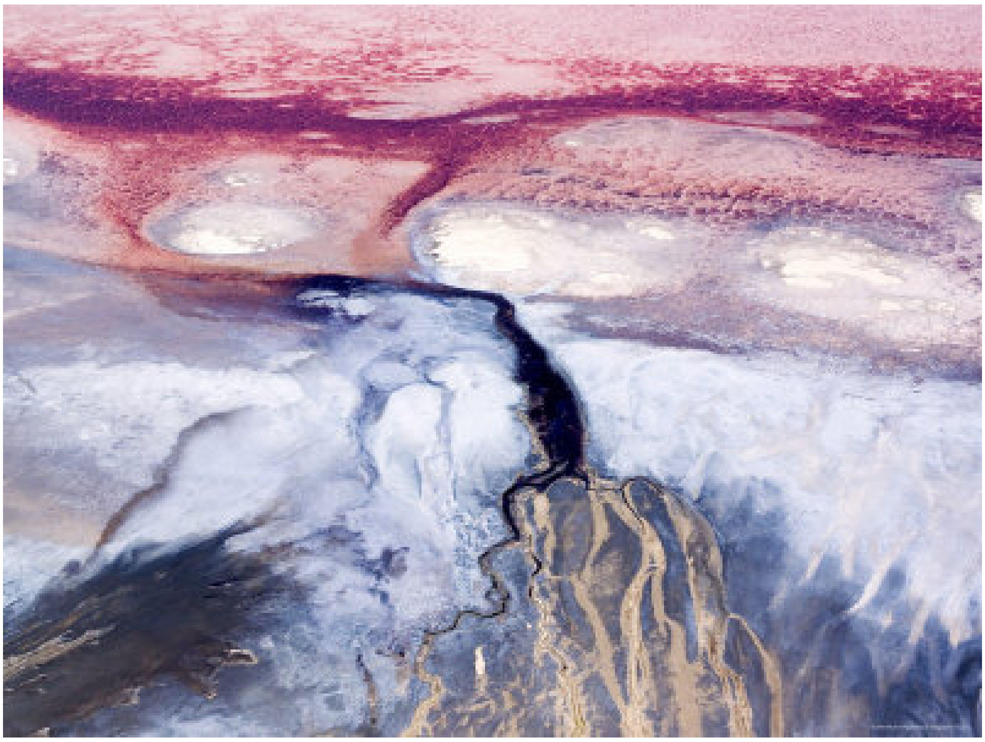

Figure 4.2: Halophile bacteria colouring Lake Natron, Tanzania reddish

- *Health and wellness:* Thermo-mineralized groundwater is used for health and wellness purposes. Groundwater with high concentrations of certain elements is (perceived as) curative for various diseases. Numerous brands of bottled mineral water, health centres (spas and sanatoria) and tourist industries are based on this relationship.
- *Salt Production*: In many ancient and modern cultures, salt is being traded as a commodity (Kurlansky, 2002). Salt production is one of the oldest chemical industries in human history. Flad et al. (2005) found evidence for a blooming salt industry in China in 2000 years B.C. In the Flemish part of Belgium and in the Netherlands, salt was produced from coastal peat in the 13th and 14th century (Stuurman, 2002). This peat had been regularly flooded by seawater. After excavation, the peat was dried and burned to produce saline ashes that were further developed into consumable salt. One other common production technologies is evaporation of brines pumped to the surface. Already more than 170 years ago, the Chinese constructed a well more than 1000 meters deep to extract brines (Vogel, 1993). The gas that was struck

during this abstraction was used to fuel the fire to evaporate the brine. CSIRO estimated that a salt industry could be developed from the dryland salinity in the Murray-Darling basin with a value of 200 million $/yr (Davidson, 2002). USGS (2007) calculated that the global salt production has increased in the period 1900- 2006 from 12 million to 251 million metric ton. The countries with the current largest shares in the global salt production are China (20%), United States (19%, 40 million of salt production in 2006 representing a market volume of about 1.4 billion dollar), Germany (8%), India (7%) and Canada (6%).

Figure 4.3: Salt mounds in Salar de Uyuni, Bolivia. The Salar de Uyuni is the world's largest (12 000 km²) and highest (3 700 m) salt flat, ca. 25 times as large as the Bonneville Salt Flats. It is the remnant of a prehistoric lake surrounded by mountains without drainage outlets. Salt is harvested in the traditional method: the salt is scraped into small mounds for water evaporation and easier transportation, dried over fire, and finally enriched with, iodine. Reference: http://commons.wikimedia.org/wiki/Image:Piles_of_Salt_Salar_de_Uyuni_Bolivia_Luca_Galuzzi_2006_a.jpg

- *Use of saline groundwater as alternative water source*: There is increasing interest in water-scarce areas to exploit and desalinize saline groundwater as an additional water resource to complement the meagre fresh water resources. For example in the town of Merredin in Western Australia, desalinization of locally pumped brackish groundwater is economically more attractive than transport fresh groundwater from distant aquifers (Davidson, 2002).

5 Managing saline groundwater

This chapter gives an overview of various measures, actions and practices conducted throughout the world to manage groundwater salinity. These measures, actions and practices can be bottom-up approaches and practiced by individuals (like farmers on their plots), groups of groundwater users (like in water users associations, or combined industries). Other measures, actions and practices are planned and practiced by governmental and non-governmental organisations that are responsible for groundwater, soil and salinity management.

Some of the measures have a mitigation objective and aim at keeping groundwater salinity levels below harmful thresholds. Other measures have a more adaptive approach and accept the high groundwater salinity encountered but adjust the groundwater use in such a way that is not harmful. The actions and measures can be broadly grouped in three categories: engineering techniques, scientific approaches (like monitoring & modelling) and behaviour and institutional approaches.

5.1 Engineering techniques

Groundwater abstraction optimization
A straightforward step to control salinization is technically optimizing of the groundwater abstraction in a certain region. In coastal aquifers prone to lateral seawater intrusion and up-coning, inland movement of the groundwater wells and the use of shallower wells decrease the salinization rate. Special fractional or skimming wells could be installed that only abstract from possibly thin layers of fresh groundwater overlying resources that are more saline. Instead of vertical wells, also horizontal abstraction drains or galleries could be used which generally cause much smaller groundwater pressure drops and hence less up-coning.

Barriers
Another group of measures is aimed at physically blocking the movement of salts. In various areas in the world tidal creeks, river estuaries and other sea inlets enormously enlarge the length of the coastline and thus the contact area between the coastal aquifers and seawater. Blocking these sea inlets with dams or barriers obstructs seawater flowing into the inlet and reduces the seawater intrusion potential in that area. In the Netherlands, the Delta works and Zuiderzee works comprising of many dams in the Rhine/Meuse estuaries prevent seawater flowing landward since the 1960's. In the state of Gujarat in India, various tidal creeks are blocked with tidal regulators. The side effect of such a barrier is that it possibly obstructs other movements as well (navigation, fish migration) and will alter the ecosystem at the landward part of the dam affecting nature and livelihoods depending on it.

Subsurface barriers or impermeable screens are developed that block the landward underground movement of seawater (Atkinson et al., 1986). An example of such a barrier is the Alamitos Barrier at the Alamitos Gap in the Central and West Coast Basin in South California. Materials used to construct such barriers are slurry walls, bio-walls, grout cut-offs, and steel sheet piles. Subsurface barriers can also be developed with hydraulic screens. In these screens, artificially increased groundwater pressures in the freshwater aquifer and /or decreased pressures in the saltwater part of the aquifer prevent the salt water flowing in. Edwards and Evans (2002) describe the case of Los Angeles city where in the 1950's, sets of closely spaced wells were drilled to inject high-quality freshwater into the ground, creating hydraulic pressure ridges.

In coastal areas that are prone to regular seawater flooding and sea-spraying various coastal protection measures consisting of e.g. levees, dikes, natural protection like dunes and mangrove vegetation and forestation with high and dense trees limit the salinization proneness. Well heads in such areas should be constructed such that possible saline water cannot intrude into the groundwater system due to submersion of well heads.

Aquifer Storage and Recovery (ASR)
A different approach in fighting salinization especially in areas of later seawater intrusion and up-coning is the artificial recharging of aquifers with fresh groundwater. The recharge increases the groundwater pressure often reversing the pressure gradient caused by coastal groundwater abstraction. This acts as a hydraulic barrier preventing the movement of the saline groundwater. Artificial recharge can be accomplished by increasing the infiltration of fresh water from surface water bodies. For example, river dams increase the water level and enhance the infiltration of (fresh) surface water into the groundwater system. Also manufactured infiltration ponds and canals (as in Gujarat) can be built that have the same effect. More advanced artificial recharge takes place through infiltration wells and underground infiltration galleries as is the case in the Dutch dune area.

The fresh water that is recharged may have various sources like harvested rainwater, river runoff, treated (desalinized) waste water, irrigation return flow and even seawater. Obviously, it only makes sense to recharge the freshwater when there are no alternative more urgent needs for that water.

ASR can first of all be approached as a storage technique where the aquifer is used as an underground reservoir. Underground reservoirs do not occupy space, need only limited maintenance and losses due to evaporation are minimized and offer a good alternative to surface water reservoirs. Secondly, ASR can also be approached as a recovery technique. Aquifers that are already salinized and rendered unsuitable for groundwater development can be (partially) recovered by flushing the dissolved salts from the groundwater system (this means both the groundwater itself and the aquifer material). Flushing will need more than just one time the volume of the brackish or saline groundwater because of solutes transport retardation and may be a long-term process. An example of such an approach is the Comprehensive Everglades Restoration Plan (CERP) in the Upper Floridan Aquifer in South Florida (Barlow, 2003).

On farmer's plot scale, flushing (or rather named leaching) sometimes is undertaken to prevent the excessive accumulation of salt in the root zone. To accomplish this, irrigation water (or rainfall) must, over the long term, be applied in excess of that needed for ET and must pass through the root zone in a minimum net amount. Leaching requirements should be minimized as far as possible in order to prevent raising the groundwater and minimize the total load to the drainage system (FAO-AGL, 2008)

Reduce water-logging induced salinization
Water-logging induced salinization occurs in areas with shallow groundwater tables and high evaporation rates. The evaporation acts as a fractionation process. When the saline water evaporates, basically only water molecules and volatile constituents change into the gaseous phase. The dissolved solutes remain behind in the non-evaporated water increasing the TDS content. Reducing this type of salinization is done by either increasing the groundwater table depth or decreasing the evaporation rate or a combination of both.

Increasing groundwater table depth can induced by various measures that limit groundwater replenishment or increase the groundwater discharge. Measures that potentially limit groundwater replenishment are for example lining of irrigation canals and lowering water levels in surface water bodies such that infiltration from surface water bodies is reduced. Improved irrigation techniques especially aimed at limiting the volume of applied water and reducing the non-beneficial return flow into the groundwater systems are common actions taken (sprinkler irrigation, drip irrigation subsoil irrigation, deficit irrigation). Measures that increase groundwater discharge are for example drainage (subsoil drains, ditches, lowering of water levels in surface water bodies), increasing groundwater abstraction by artificial pumping or planting high water consumptive vegetation like eucalyptus and acacia, so-called biological drainage (Aslam and Prathapar, 2006).

Evaporation of shallow groundwater especially takes place when the groundwater moves upward into the non-saturated part of the soil as a result from capillary rise. Deep tillage increase soil pores, decreases capillary potential of soils, and thus acts as a measure to decrease groundwater salinization in areas of shallow groundwater levels. Any technique that reduces evaporation (in irrigation obviously the non-beneficial evaporation) helps to limit this type of salinization (Ambast et al., 2007). Measures that are undertaken to reduce evaporation on farmer plot level are for example shielding with screens and high trees that create shades and reduce temperature. Also technical measures that reduce wind speed (most important driver determining evaporation rate) like mulching and high vegetation plot perimeters are used to reduce groundwater salinization in these cases.

Saline effluent, transport, treatment disposal
Drainage effluent from intensive cropping irrigation areas, industrial effluent and domestic wastewater may contain very high salt contents. Uncontrolled disposal or release of these waters may lead to introducing salts into the groundwater system. In order to prevent this type of salinization the following steps are undertaken in many locations around the globe.

First of all the volume of effluent produced and the level of contamination in the effluent should be kept as low as possible. Irrigation and industrial water use efficiency measures help to control the effluent volume. Using less chemicals in production processes (fertilizer in the agriculture, solvents in the industrial sector) will help to limit the salinity. Secondly, the collection and transport system of the effluent (like in sewer systems, industrial wastewater infrastructure and irrigation drainage) should be constructed and maintained such there is no non-intended seepage from it. Prior to the effluent entering the groundwater system (e.g. since it is re-used as irrigation water) it should ideally be purified and the salts removed by desalinisation techniques (see next entry). In some parts of Southern Punjab, Pakistan, irrigation drainage effluent is collected and disposed in evaporation ponds (Aslam and Prathapar, 2006).

Desalinisation of saline (ground)water
Desalination processes separate dissolved solutes from brackish and saline feedwater by means of phase-change processes (distillation, freezing) or membrane processes (reversed osmosis, electro-dialysis, nano- and ultra-filtration). This process needs relatively advanced technologies and is energy-intensive. Therefore, the decentralization is financially demanding. Because of the high costs involved, desalinisation is often only used for high-end water uses in high technology, high GDP countries where economically more attractive alternative sources are not available like in the Middle East and Mediterranean (BRL, DHV, 2004).

5.2 Scientific approaches

Monitoring and assessment
Managing groundwater salinity is about making informed decisions. It is of paramount importance to know the extent and severity of the groundwater salinity in order take appropriate actions. For this, one needs to monitor and measure the groundwater salinity. Monitoring of groundwater salinity by measuring the electric conductivity and/or TDS content is the standard practice.

A world-wide inventory on groundwater monitoring conducted by IGRAC in 2004 (Jousma and Roelofsen, 2004) revealed that the countries listed below have included salinity in their monitoring programmes:

- Africa: Botswana, Central African Republic, Djibouti, Mauritius, South Africa in
- Asia: China, India, Japan, Korea, Malaysia, Myanmar;
- Europe: Belgium, Denmark, Finland, Hungary, Netherlands, Romania, Slovenia, Switzerland;
- North America: Canada, USA;
- Oceania: Australia, New Zealand;

- Central and South-America: Argentina, Barbados, Chile, Uruguay

Modelling
To analyze the salinity genetics and dynamics and to estimate effects of interventions in the groundwater systems and land use on groundwater salinity, flow and solutes transport numerical models are used. Various computer codes and types of software exist that can perform these simulations, analyses and data visualization like MT3D, MOCDENSE, SEAWATER, Feflow. Scientific documentation on groundwater salinity modelling seems to focus mainly on two types of groundwater salinity: i.e. lateral seawater intrusion and up-coning (like the SWIM studies) and salinity caused by irrigation. This is not surprising as the economic interests of these zones are high.

5.3 Behaviour and institutional approaches

Groundwater abstraction reduction
A straightforward measure to decrease the process of salinization from lateral seawater intrusion and up-coning is by limiting the amount of groundwater abstracted. In order to do this, water demand management should be adopted. Various water saving measures are implemented at locations around the world that have high salinization proneness. Naturally, also other drivers like an overall water scarcity, force people to adapt to such water saving practices. Possible water-saving measures are reduction of non-beneficial evaporative and leakage losses, increase of irrigation efficiency, a change to less water demanding production processes and land uses and to find alternative sources of water other than groundwater (surface water or re-use of waste water).

Salt tolerant crops
Groundwater salinity is also managed by adjusting groundwater use to poorer groundwater quality levels. In many agricultural areas where only marginal quality water is available and where soil conditions are negatively affected by salinity, farmers are still able to grow crops profitably by changing to more salt-tolerant crops. Often the crop adaptation is accompanied by nutrients augmentation (in fertilizers) and soil quality improvement (e.g. adding gypsum sulphuric acid, and iron pyrite to reduce the negative effects of soil sodicity).

Conjunctive use of water
In cases of marginal quality groundwater, it makes sense to use this water in conjunction with better types of water. The poor quality groundwater could physically be blended with more fresh water to provide water with an acceptable salinity level for application. Alternatively, the poor quality groundwater could be applied in an alternating fashion with better quality water. Farmers in Pakistan (Aslam and Prathapar, 2006) alternatively apply groundwater with high TDS and better quality surface water from irrigation canals on their lands. The salinity levels in the groundwater in this region are not that high that they cause immediate negative effects to plant growth. The freshwater is used to meet the evaporative crop demand but also to flush the plot. It prevents that soil salinity builds up significantly in the end.

Institutional instruments
Applying engineering technologies and adapting groundwater use behaviours does not go without costs albeit direct financial costs or more indirect and hidden costs. Farmers in salinity prone areas often rationally measure the investment costs needed for fighting salinity against the losses caused by salinity in case of non-action. On a larger scale, policymakers, agriculturists and natural resources managers need to estimate how much groundwater salinity is allowed in an certain area before complex and strongly interrelated systems of nature and society are significantly affected. Some of the consequences caused by salinity in such complex systems may be irreversible or may trigger even larger scale problems (like socio-economic problems caused by migration and unemployment of farmers that had to abandon their land due to severe salinity problems)

The governmental and non-governmental organisations dealing with groundwater management and those dealing with soil management, agriculture and livelihood development do have a responsibility to help make individuals mitigate, adapt to or compensate for, the salinity problems.

Institutional instruments that are practiced to control groundwater salinity are:

- regulatory (like well registration, licensing, groundwater abstraction rights and quota, land use restrictions, emission rules),
- economic (subsidies for individuals or groups/sectors to invest in new technologies to manage salinity, investments in governmental ASR programmes, environmental taxes to discourage salinity increasing practices, compensation for financial losses caused by salinity)
- advisory (enabling access to information, expertise, funding and creating awareness, training and extension).

Policy and plan development

The technical, scientific, behavioural and institutional approaches of salinity management (ideally) come together in the development of policies and plans that deal with groundwater salinity in an integrated way. Such a policy should contain an integrated and strategic vision on groundwater salinity management for a certain area and for a certain period. It should make clear what can be done to fight groundwater salinity and who is responsible. Such a policy document should preferably not restrict itself to groundwater salinity only but integrate this in a wider environment of groundwater management, soil management, integrated coastal zone management, livelihood and economic sector development and spatial planning and possibly others. Examples of such policy are the National Action Plan on Salinity and Water Quality of the Australian government and the Salinity Ingress Prevention Circle in the State of Gujarat in India.

It makes sense to include the various governmental and non-governmental organisations working in this wider environment to develop such policies. The participation of public is of paramount importance to find ground truth solutions and get the necessary support needed for implementation and compliance. A good example of such an approach is the Coastal Salinity Prevention Cell, a combination of NGOs, the government of Gujarat and the people in affected areas of Saurashtra that combat salinity ingress.

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6 Discussion and concluding remarks

6.1 Discussion of results

Chapter 4 already discussed how saline groundwater might affect humans, societies and nature. Their vulnerability to groundwater salinity is obviously depending on how they are using and being dependent on groundwater. In this section, it is tried to define the global scope and severity of groundwater salinity by estimating the areal extent of high groundwater salinity and by the number of people potentially affected by groundwater salinity.

Areal extent

The global geographical distribution of saline groundwater obtained in this study is analyzed statistically in a GIS. Table 6-1 gives the areal extent where according to this study groundwater salinity to a depth of 500 meters is significant. Entries are given in a cross table grouped by the global groundwater regions (rows) and by the salinity generic types (columns). The unit in this table is in 1.000's of km^2. For the generic type A3 (flooding by the sea) it is assumed that the distance of inland influence on groundwater salinity is 1 km. For the generic type A4 (lateral seawater intrusion) it is assumed that the general distance of inland influence on groundwater salinity is 25 km.

The total area where groundwater salinity at shallow or intermediate depth is considered high in this study approximates 24 million km^2. This is about 16% of the total land area on earth. The generic type B1 (evaporation of shallow groundwater) and B2 (dissolution) or a combination of the two contribute most to this saline groundwater area with respectively contributions of 20, 26 and 13%. The next most important areal-wise contributor to groundwater salinity is connate water (A1) with a contribution of 14%. No significant groundwater salinity occurrences caused by membrane effects are found in this study. In addition, the effect of anthropogenic pollution on the TDS-content of groundwater is not significant on this scale.

In the Global Groundwater Region 25 (Basins of West and Central Asia), the largest area with high groundwater salinity is found. It contributes 14% to the total groundwater salinity area. The Global Groundwater Regions 7 (Lowlands of South America), 11 (lowlands of Europe), 24 (mountain belt of central and eastern Asia) and 35 (Eastern Australia) contribute individually for about 6-7 % to the total groundwater salinity area.

Note that based on this study is not possible to estimate the volume of saline groundwater. First, it only looks at saline groundwater to a maximal depth of 500 meters below surface. Secondly, as is mentioned before, in this study a certain location is defined to have saline groundwater even when only a part of the column of 500 meters is containing saline groundwater. The depth horizons and thicknesses of saline groundwater layers at particular locations have not been delineated in this study.

Number of people potentially affected

We combined the global geographical distribution of groundwater salinity with world population data of the year 2000 to estimate the number of people potentially affected by groundwater salinity. The unit used in the table 6.2 is millions of people.

According to this study, about 1.1 billion people live in areas with groundwater salinity at shallow and intermediate depths. The generic types contributing most to the amount of groundwater salinity 'affected' people are irrigation (C1, 25%), lateral seawater intrusion (A4, 17%), dissolution (B2, 17%) and igneous activities (15%).

Table 6-1: Land area (in millions of km^2) where likelihood of groundwater salinity at shallow and intermediate depths is significant

Global Groundwater Region	Generic type of Groundwater salinity															Total per global groundwater region	
	Marine origin (A0)	Combination of A1, A2 and A3	Connate groundwater (A1)	Marine transgression (A2)	Current flooding (A3)	Lateral seawater intrusion (A4)	Terrestrial origin (B0)	Combination of B1 and B2	Evaporation (B1)	Dissolution (B2)	Membrane effects (B3)	Igneous activity (B4)	Irrigation (C1)	Anthropogenic pollution (C2)	Undefined origin (D0)		
1	1	0	0	0	0	42	0	139	0	0	0	0	5	0	0	*187*	1%
2	0	0	0	0	0	0	0	701	0	0	0	0	0	0	23	*723*	3%
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*0*	0%
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*0*	0%
5	1	0	266	0	0	101	0	0	0	0	0	0	0	0	9	*378*	2%
6	14	0	4	0	0	28	0	3	164	0	0	0	0	0	0	*213*	1%
7	0	0	1,435	0	0	5	0	0	192	0	0	0	0	0	42	*1,673*	7%
8	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	*5*	0%
9	0	0	614	0	0	0	0	0	0	0	0	0	0	0	0	*614*	3%
10	0	0	0	418	0	6	0	0	0	11	0	3	0	0	0	*439*	2%
11	87	0	0	0	0	0	0	86	228	704	0	0	0	0	300	*1,405*	6%
12	1	32	0	0	0	0	0	0	0	51	0	0	0	0	0	*83*	0%
13	0	0	0	0	0	25	0	13	8	0	0	0	0	0	0	*46*	0%
14	0	0	826	0	0	124	0	21	167	0	0	0	0	0	0	*1,137*	5%
15	0	0	60	0	0	211	0	0	0	4	0	0	0	0	46	*322*	1%
16	0	0	0	0	0	26	0	61	74	30	0	0	0	0	81	*272*	1%
17	0	0	9	0	0	82	108	3	25	5	0	9	0	0	11	*251*	1%
18	0	0	0	0	0	29	12	14	0	20	0	17	0	0	0	*92*	0%
19	0	0	6	0	0	116	0	115	0	0	0	0	0	0	0	*237*	1%
20	0	0	0	0	0	0	0	0	130	16	0	0	0	0	0	*146*	1%
21	0	0	0	0	0	0	0	0	0	929	0	0	0	0	0	*929*	4%
22	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	*12*	0%
23	0	0	0	0	6	42	0	0	0	0	0	976	0	0	0	*1,024*	4%
24	0	0	0	0	1	76	0	126	287	793	0	77	46	0	0	*1,406*	6%
25	0	0	0	0	0	0	0	1,755	909	405	0	0	185	0	57	*3,311*	14%
26	0	0	22	0	0	17	0	71	280	540	0	145	71	0	4	*1,150*	5%
27	0	0	0	0	0	0	0	0	748	17	0	0	0	0	0	*765*	3%
28	0	0	9	56	1	67	0	0	0	0	0	0	670	0	0	*803*	3%
29	0	0	35	0	1	43	0	0	65	183	0	0	371	0	0	*699*	3%
30	0	0	5	0	0	73	0	8	0	1	0	3	0	0	0	*89*	0%
31	0	0	10	11	0	76	0	27	38	913	0	0	121	0	0	*1,195*	5%
32	0	0	0	9	5	68	0	0	0	64	0	0	310	0	0	*455*	2%
33	0	0	0	0	5	105	0	0	0	173	0	489	33	0	0	*805*	3%
34	0	0	0	0	1	0	0	0	58	573	0	0	158	0	0	*791*	3%
35	0	0	0	0	0	31	0	0	1,430	0	0	0	0	0	0	*1,461*	6%
36	0	0	0	0	0	7	0	0	0	733	0	173	0	0	0	*913*	4%
Total per generic type	*104*	*32*	*3,302*	*494*	*19*	*1,402*	*120*	*3,142*	*4,803*	*6,164*	*0*	*1,904*	*1,971*	*0*	*573*	*24,030*	100%
	0%	0%	14%	2%	0%	6%	0%	13%	20%	26%	0%	8%	8%	0%	2%	100%	

Table 6-2: Number of people (in millions) living in areas with groundwater salinity at shallow and intermediate depths

Global Groundwater Region	Marine origin (A0)	Combination of A1, A2 and A3	Connate groundwater (A1)	Marine transgression (A2)	Current flooding (A3)	Lateral seawater intrusion (A4)	Terrestrial origin (B0)	Combination of B1 and B2	Evaporation (B1)	Dissolution (B2)	Membrane effects (B3)	Igneous activity (B4)	Irrigation (C1)	Anthropogenic pollution (C2)	Undefined origin (D0)	Total per global groundwater region	
	Generic type of Groundwater salinity																
1	0	0	0	0	0	12	0	1	0	0	0	0	0	0	0	12	1%
2	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	5	0%
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
5	0	0	7	0	0	10	0	0	0	0	0	0	0	0	0	18	1%
6	1	0	1	0	0	2	0	0	1	0	0	0	0	0	0	5	0%
7	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	2	0%
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
9	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	19	2%
10	0	0	0	9	0	0	0	0	0	3	0	0	0	0	0	11	1%
11	62	0	0	0	0	0	0	1	1	0	0	0	0	0	0	64	5%
12	0	7	0	0	0	7	0	0	0	10	0	0	0	0	0	25	2%
13	0	0	0	0	0	4	0	1	0	0	0	0	0	0	0	4	0%
14	0	0	38	0	0	5	0	0	2	1	0	0	0	0	0	45	4%
15	0	0	2	0	0	15	0	0	0	0	0	0	0	0	3	20	2%
16	0	0	0	0	0	9	0	0	0	0	0	0	0	0	1	11	1%
17	0	0	0	0	0	0	2	0	1	0	0	1	0	0	0	4	0%
18	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	3	0%
19	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	3	0%
20	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0%
21	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	4	0%
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
23	0	0	0	0	0	41	0	0	0	0	0	121	0	0	0	163	14%
24	0	0	0	0	0	11	0	1	5	0	0	0	13	0	0	31	3%
25	0	0	0	0	0	0	0	43	7	10	0	0	23	0	5	87	7%
26	0	0	1	0	0	3	0	2	7	18	0	6	10	0	0	48	4%
27	0	0	0	0	0	0	0	0	8	2	0	0	0	0	0	11	1%
28	0	0	0	0	0	16	0	0	0	0	0	0	163	0	0	179	15%
29	0	0	19	0	0	6	0	0	11	123	0	0	0	0	0	158	13%
30	0	0	0	0	0	4	0	0	0	1	0	0	0	0	0	5	0%
31	0	0	0	2	0	8	0	0	12	10	0	0	12	0	0	45	4%
32	0	0	0	5	0	14	0	0	0	5	0	0	75	0	0	98	8%
33	0	0	0	0	0	33	0	0	0	17	0	45	0	0	0	95	8%
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
35	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	3	0%
36	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0%
Total per generic type	63	7	88	15	0	204	3	56	60	205	0	175	296	0	9	1,080	100%
	5%	1%	7%	1%	0%	17%	0%	5%	5%	17%	0%	15%	25%	0%	1%	100%	

It is not surprising that the first two generic types affect most people since it are these very same people who are the drivers for these salinisation processes (with high numbers of people living in fertile agricultural areas and along the coast and in deltas this seems logical).

The Global Groundwater Regions with highest population density contribute most to the groundwater salinity affected people: The lowlands of eastern China (28, 15%) the plains and deltas of Ganges and Brahmaputra rivers (29, 13%) and the Northwestern Pacific margin (23, 13%).

Whether people living in the groundwater salinity affected areas are really being affected by the salinity is very much dependent on their groundwater use. First, when people are hardly using any groundwater, their vulnerability to groundwater salinity hazards is obviously low. This is for example the case for most people living in the igneous active area of East Asia (the ring of fire in Japan, Philippines, and Indonesia). The population density on these islands is high and the occurrence of saline groundwater is widespread but manifests itself mostly at localized spots only. Climate in this zone is humid with relatively large amounts of rainfall. This leaves the people in these areas in most cases with sufficient surface water to meet their water demand. Secondly, the map denotes areas as having saline groundwater even when only a fraction of the depth profile is actually containing groundwater with a high salinity level. This is for example the case in the Netherlands where high groundwater salinity is found. However, the groundwater salinity only manifests itself in a limited part of the depth profile up to 500 meters below surface level. This leaves sufficient fresh groundwater to be used for drinking water production for this small but densely populated country. The number of 1.1 billion people potentially affected by groundwater salinity should therefore be considered as a worst-case figure.

6.2 Concluding remarks

Groundwater salinity is a widespread problem in our world. It can cause health problems, decrease agricultural yields and profits, destroy fertile agricultural lands, jeopardize livelihoods, increase costs of infrastructure maintenance, costs of industrial processes and change or destroy eco-systems. All this of course is very much dependent on how the groundwater is used to meet the water demand for these processes and activities and dependent on the level of salinity of the groundwater applied.

To be able to manage saline groundwater, researchers, water resources specialists, policy makers and politicians need information on the scope, distribution, dynamics and severity of groundwater salinity. This study is a contribution to provide such essential information for this broad group of people and aims to enhance their general understanding of groundwater salinity, promote early diagnosis of possible changes and widen their inspiration for selecting effective measures for interventions.

This study provides information on different types of origin of groundwater salinity, on natural and anthropogenic drivers affecting groundwater salinity dynamics. It furthermore gives insights in how groundwater salinity may negatively (or positively) affect activities and processes in which saline groundwater is used. The study gives a broad overview of possible technical, scientific, managerial and institutional measures that are undertaken worldwide to mitigate or adapt to groundwater salinity.

The core of this study however consists of a description, characterization and geographical delineation of the global occurrence of saline groundwater. For each of IGRAC's Global groundwater regions a wide range of documented information on Groundwater salinity is collected and summarized in the tables of annex 2. Moreover, the geographical delineation of global groundwater salinity is mapped in annex 1.

The geographical delineation of groundwater salinity as printed on the map is estimated from a combination of hard data and proxy information and should be considered as areas with a high probability of groundwater salinity occurrence. We consider this as a first version of the map and will update the information and improve the reliability of the geographical delineation based on feedback coming from the groundwater community worldwide.

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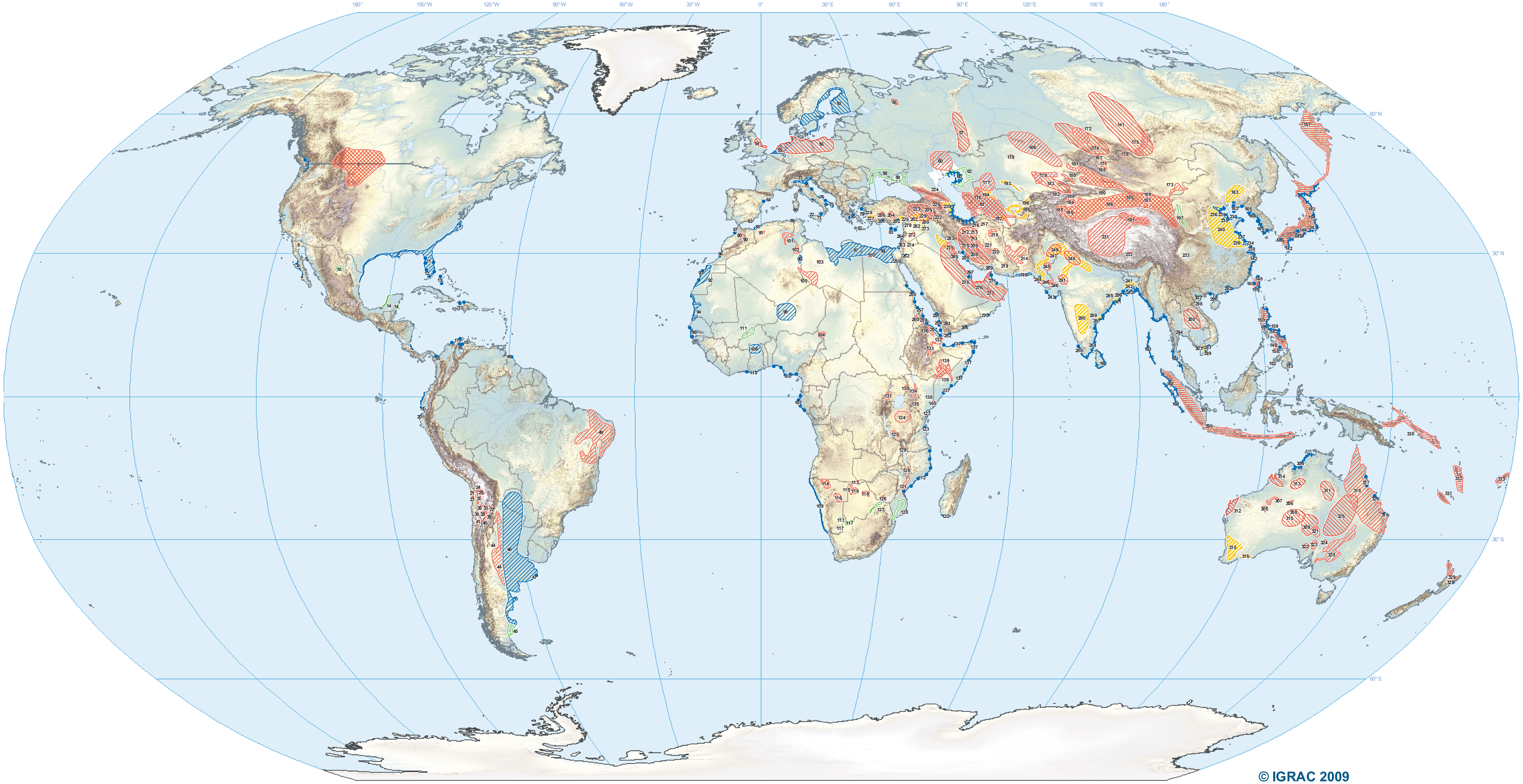
Annex 1: Global overview of Saline Groundwater Occurrence and Genesis, draft version

igrac
International Groundwater Resources Assessment Centre

Global Overview of Saline Groundwater Occurrence and Genesis

- draft version -

Scale 1 : 50 000 000



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Legend

Saline and brackish groundwater by genesis

Occurrences at shallow and intermediate depths (less than approximately 500 m)

- Marine origin
- Transgression
- Flooding
- Lateral seawater intrusion & up-coning
- Irrigation

- Marine origin
- Connate
- Marine transgression
- Lateral seawater intrusion & up-coning
- Combination of connate, transgression and recent flooding
- Natural terrestrial origin
- Evaporation

- Dissolution
- Igneous activity hydrothermal mineral water
- Combination of evaporation & dissolution
- Irrigation
- Pollution
- Unspecified origin

Elevation

ice and > 8000 m

Sea Level : 0 m

Geographic elements

Political borders

lakes

rivers

Cartographic editing/GIS
F. van Weert
J. Reckman
J. van der Gun
C.M. van Kempen

Base maps
Geographic features and shaded relief: ESRI data and maps (2006)
Elevation: ETOPO1 (Amante, C. and B.W. Eakins, 2008)

Map projection
Robinson projection, geographic coordinates,
spheroid WGS84, longitude of central meridian 0º.

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of the Netherlands through Partners for Water.

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Annex 2: Global description of the distribution of saline groundwater at shallow and intermediate depths

Two types of code are used throughout the text:
- (A1) to (D0) refers to different types of salt water source
- (333) refers to individual groundwater salinity occurrences on the map

North and Central America & the Caribbean

Global Groundwater Region 1: Western mountain belt of North and Central America	
Countries included	Parts of Canada, Unites States, Mexico, Guatemala, Belize, Honduras, Nicaragua and Costa Rica, all of El Salvador and Panama
Generalized hydrogeological setting	This region, the Westernmost zone of the continent, includes highly elevated folded areas of North and Central America, belonging to the Pacific and Cordilleran Belts. Sedimentary and metamorphic rocks underlie the region. After these belts were formed, extensive less deformed basins dominated by volcanic rocks superimposed them. There are large variations in climate: above-average rainfall in mountain zones, low rainfall in arid zones, permafrost conditions in the North, and tropical temperature regimes in the South. Main physiographic units or geological provinces: a) Alaska b) Cordilleran Orogen of Canada c) Pacific Mountain System d) Columbia Plateau e) Basin and Range f) Colorado Plateau g) Rocky Mountains System h) Central American ranges (including Mexican Sierras) Groundwater resources are variable. In the mountains, they are associated with glacial and fluvial aquifers in faulted troughs or with intermontane basins. The volcanic regions in Central America contain some of the most productive aquifers. Coastal aquifers are present in structural basins filled with marine and alluvial sediments.
Adequacy of information accessed on saline groundwater	Variable degree of information, with the USA being the best documented country. Large parts of Canada are relatively unexplored as regards groundwater; even more scarce is the information on the presence of saline and brackish groundwater.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* the presence of saline groundwater at shallow and intermediate depths (< 500 m deep) so far is only fragmentary known in this region. Marine origin is dominant. *Saline groundwater of marine origin* is known to affect the Gulf Islands aquifer system on the Canadian Western coast (1), probably because of *seawater intrusion* (A4). Seawater intrusion is also known to affect coastal aquifers on the Northern shores of San Francisco Bay (2) and Monterey

	Bay (3) in California, USA. Further South, in Mexico, seawater intrusion is reported to affect 15 aquifers, of which a few larger ones are located in Baja California (4) (Pacific Coast) and in the Noroeste province along the Gulf of California (5). Locally, there are also narrow zones of saline groundwater along the Pacific coast of Central America (6 and 7); it has a marine origin, but it is unknown whether the zones are affected or threatened by seawater intrusion (A0). Brackish groundwater of *anthropogenic origin*, resulting from soil salinization due to irrigation (C1) occurs in an overexploited aquifer on the Northern coast of the Gulf of California (8). Brackish groundwater as a result of a *combination of evaporation and dissolution* (B5) also occurs in the High Plains of the USA and the Great Plains of Canada (9)
Current or potential threats of saline groundwater to the interests of society or ecosystems	Threats seem mainly related to seawater intrusion (at selected locations along the Pacific coast) and to irrigation.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Not identified.
Human responses to threats and or opportunities(management)	-
Impact of expected or observed global change	-
Selected references	Rivera, A., 2005. How well do we understand groundwater in Canada? Geological Survey of Canada, (http://ess.nrcan.gc.ca/2002_2006/gwp/index_e.php), consulted in October 2008 Chen, Z., Grasby, S.E. and K.G. Osadetz, 2004. Relation between climate variability and groundwater levels in the Upper Carbonate aquifer, Southern Manitoba, Canada, *Journal of Hydrology*, Vol. 290, pp 43-62 Natural Resources Canada, 2006. Groundwater Program, (http://ess.nrcan.gc.ca/2002_2006/gwp/index_e.php) Last, W., and F. Ginn, 2005. Saline systems of the Great Plains of Western Canada: an overview of the limnology and paleolimnology, (www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1315329) US Geological Survey, no date. Ground Water Atlas of the United States, (http://capp.water.usgs.gov/gwa/gwa.html), consulted in October 2008 Jiménez, B., and L. Marín, 2004. El agua en Mexico vista de la Academia, Academia Mexicana de Ciencias Conagua, 2007a. Estadísticas del agua en México, Edición 2007 Conagua, 2007b. Portal on water in México (http://www.conagua.gob.mx/Conagua/Espaniol/TmpContenido.aspx?id=24002a7d-7cf5-4153-adeb-6e36ce1dff13|SISTEMA%20NACIONAL%20DE%20INFORMACIÓN%20DEL%20AGUA|10|0|0|0|0), consulted in October 2008 Weyl, R., 1980. Geology of Central America, 2nd edition, *Beiträge zur regionalen Geologie der Erde*, Gebr. Bornträger, Berlin US Corps of Engineers, 2001-2005. Water Resources of Latin America and the Caribbean (www.sam.usace.army.mil/en/wra/wra.html) UNESCO/PHI and OEA, 2007. Sistemas acuíferos transfronterizos en las

	Americas, Evaluación preliminary Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6 Read, H. H. and J. Watson, 1975. *Introduction to Geology, Volume 2: Earth history*, Macmillan, London

Global Groundwater Region 2: Central plains of North and Central America	
Countries included	Parts of Canada, United States and Mexico
Generalized hydrogeological setting	This region is located in the heart of North America and includes topographically low areas with gently rolling to flat topography. Except at its Northern edge, there is no boundary with the sea. Thick sequences of sediments deposited in marine, alluvial, glacial and aeolian environments cover the Precambrian Basement. Climate is predominantly dry. Permafrost is present in the North. Main physiographic units or geological provinces: a) Interior Platform of Canada b) Interior Plains of USA c) Interior Highlands d) Sierra Madre Oriental Groundwater resources are abundant and the region is characterised by large volumes of stored groundwater. Large regional aquifers occur in porous or fractured consolidated sediments and in large alluvial areas (e.g. High Plain aquifer in USA). Glacial sediments in the Northern parts may form local aquifers.
Adequacy of information accessed on saline groundwater	Variable degree of information, with the USA being the best documented country. Large parts of Canada are relatively unexplored as regards groundwater; even more scarce is the information on the presence of saline and brackish groundwater.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* The reservoirs offered by several thousands of metres thick sedimentary strata in this region contain huge quantities of fresh groundwater, but the stagnant water masses at great depth – since long isolated from the active branches of the hydrological cycle – are predominantly saline. At depths less than 500 m, brackish or saline groundwater is not predominant, but it is present as well, in distinct zones. *Dissolution of salt from evaporates combined with superficial evaporation* (B5) are reported to be important sources of saline groundwater in this region. This is observed widely on the High Plains in the USA and on the Canadian Great Plains (9), an area with very complex salinity pattern and salinization mechanisms. Evaporates are not uncommon within the up to 5000 m thick sediment sequence in this region - especially in the Paleozoic and Mesozoic strata - and they are considered as a major source of salinity of the many saline to brackish lakes scattered over the region and of the connected groundwater systems. An example of the latter is the large Canadian Winnipeg aquifer that extends Southwards into USA under the name 'Ordovician aquifer'. The Canadian part is partly salinized (Western part). However, the shallow unconsolidated deposits may be brackish or saline as well. Many shallow groundwater systems in the same region have internal drainage only. As far as they contain brackish or saline

	groundwater, this may be caused by *groundwater discharge by evaporation*, under semi-arid conditions (B1). Chemical characteristics of salinity in the Great Plains region are variable, with strong representation of sulphates. Brackish and/or saline groundwater is reported to be present as well in the adjacent central basins of Northern Mexico (Cuencas Centrales del Norte) (10), but the origin of the salinity is not documented (D0).
Current or potential threats of saline groundwater to the interests of society or ecosystems	In this region, keeping saline groundwater under control is highly important to safeguard groundwater use for various purposes, to maintain a suitable living environment and to support agriculture and ecosystems. Groundwater abstraction is of vital importance for a large percentage of the population.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Since semi-arid climates prevail, this region is affected by water scarcity. On the other hand, large volumes of brackish groundwater are available in this region at convenient depths. Therefore, it is realistic to consider development of brackish groundwater as a potential additional source to meet increasing water demands in the future.
Human responses to threats and or opportunities(management)	-
Impact of expected or observed global change	-
Selected references	Chen, Z., Grasby, S.E. and K.G. Osadetz, 2004. Relation between climate variability and groundwater levels in the Upper Carbonate aquifer, Southern Manitoba, Canada, *Journal of Hydrology*, Vol. 290, pp 43-62 Conagua, 2007a. Estadísticas del agua en México, Edición 2007 Conagua, 2007b. Portal on water in México (http://www.conagua.gob.mx/Conagua/Espaniol/TmpContenido.aspx?id=24002a7d-7cf5-4153-adeb-6e36ce1dff13|SISTEMA%20NACIONAL%20DE%20INFORMACIÓN%20DEL%20AGUA|1|0|0|0|0), consulted in October 2008 Dennehy, K.F., 2004. National perspective on saline aquifers, Water Desalination and Reuse Strategies for New Mexico, New Mexico Water Resources Research Institute Hutson, S.S., Barber, N.L., Kenny, J.F., Linsey, K.S., Lumia, D.S., and Maupin, M.A., 2004. Estimated use of water in the United States in 2000: Reston, Va., U.S. Geological Survey Circular 1268 Jiménez, B., and L. Marín, 2004. El agua en Mexico vista de la Academia, Academia Mexicana de Ciencias Last, W., and F. Ginn, 2005. Saline systems of the Great Plains of Western Canada: an overview of the limnology and paleolimnology, (www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1315329) Natural Resources Canada, 2006. Groundwater Program, (http://ess.nrcan.gc.ca/2002_2006/gwp/index_e.php) Rivera, A., 2005. How well do we understand groundwater in Canada? Geological Survey of Canada, (http://ess.nrcan.gc.ca/2002_2006/gwp/index_e.php), consulted in October 2008 UNESCO/PHI and OEA, 2007. Sistemas acuíferos transfronterizos en las Americas, Evaluación preliminary US Corps of Engineers, 2001-2005. Water Resources of Latin America and the Caribbean (www.sam.usace.army.mil/en/wra/wra.html), consulted at October 2008 US Geological Survey, no date. Ground Water Atlas of the United States, (http://capp.water.usgs.gov/gwa/gwa.html), consulted in October 2008 Weyl, R., 1980. Geology of Central America, 2nd edition, *Beiträge zur regionalen Geologie der Erde*, Gebr. Bornträger, Berlin

	Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Global Groundwater Region 3: Canadian shield	
Countries included	Greenland, and parts of Canada and United States
Generalized hydrogeological setting	This region includes the low to moderate elevated areas of the Canadian Shield. The region's topography is mainly a result of the effects of glacial action. Precambrian crystalline rocks cover most of the region. Locally remains of sedimentary covers (mainly limestone) are found. Region receives moderate precipitation (often as snow). Continuous permafrost is present in the Northern half. Main physiographic units or geological provinces: a) Seven geological provinces of Canadian shield b) Innuitian Orogen c) Hudson Bay Lowlands d) Arctic Platform e) St. Lawrence Platform f) Laurentian Platform of USA g) Greenland Groundwater resources are limited. Groundwater is restricted to local pockets of weathered or fractured consolidated rocks or to shallow layers of fluvial and glacial sediments. Certain areas are susceptible to arsenic contamination.
Adequacy of information accessed on saline groundwater	Very limited information. Lack of information suggests that saline groundwater is not an issue.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* no indications have been found on the presence of significant bodies of saline groundwater at shallow and intermediate depths (< 500 m deep).
Current or potential threats of saline groundwater to the interests of society or ecosystems	Given the absence of known significant bodies of saline groundwater at shallow and intermediate depths, no threats have been identified.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Given the absence of known significant bodies of saline groundwater at shallow and intermediate depths, no opportunities have been identified.
Human responses to threats and or opportunities(management)	-
Impact of expected or observed global change	-

Selected references	Natural Resources Canada, 2006. Groundwater Program. (http://ess.nrcan.gc.ca/2002_2006/gwp/index_e.php), consulted in October 2008 Read, H. H. and J. Watson, 1975. *Introduction to Geology, Volume 2: Earth history*, Macmillan, London Rivera, A., 2005. How well do we understand groundwater in Canada? Geological Survey of Canada, (http://ess.nrcan.gc.ca/2002_2006/gwp/index_e.php), consulted in October 2008 UNESCO/PHI and OEA, 2007. Sistemas acuíferos transfronterizos en las Americas, Evaluación preliminar US Geological Survey, no date. Ground Water Atlas of the United States, (http://capp.water.usgs.gov/gwa/gwa.html), consulted in October 2008 Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Global Groundwater Region 4: Appalachian highlands	
Countries included	Part of Canada and United States
Generalized hydrogeological setting	This region includes the high-elevated Eastern part of North America belonging to the Appalachian Orogenic belt. Metamorphic and igneous rocks are present. After the belt was deformed, extensive less deformed basins dominated by sedimentary rocks superimposed it. Climate is predominantly humid. Main physiographic units or geological provinces: a) Appalachian Orogen in Canada b) Appalachian Highlands in USA Groundwater resources are variable. The principal aquifers are found in carbonate rocks and sandstones (e.g. Valley and Ridge aquifers). The high elevated areas have limited groundwater resources with local shallow aquifer systems in sand and gravel deposits of glacial and alluvial origin.
Adequacy of information accessed on saline groundwater	No significant information on saline groundwater, with the USA being the best documented country.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* absence of information on groundwater suggests that saline groundwater at shallow and an intermediate depth (< 500 m deep) is not abundantly present or at least is not an issue.
Current or potential threats of saline groundwater to the interests of society or ecosystems	Given the absence of known significant bodies of saline groundwater at shallow and intermediate depths, no threats have been identified.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Given the absence of known significant bodies of saline groundwater at shallow and intermediate depths, no opportunities have been identified.
Human responses to threats and or opportunities(management)	-
Impact of expected or observed global change	-
Selected references	Natural Resources Canada, 2006. Groundwater Program.

	(http://ess.nrcan.gc.ca/2002_2006/gwp/index_e.php), consulted in October 2008 Rivera, A., 2005. How well do we understand groundwater in Canada? Geological Survey of Canada, (http://ess.nrcan.gc.ca/2002_2006/gwp/index_e.php), consulted in October 2008 UNESCO/PHI and OEA, 2007. Sistemas acuíferos transfronterizos en las Americas, Evaluación preliminar US Geological Survey, no date. Ground Water Atlas of the United States, (http://capp.water.usgs.gov/gwa/gwa.html), consulted in October 2008 Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Global Groundwater Region 5: Caribbean islands and coastal plains of North and Central America	
Countries included	Cuba, Jamaica, Haiti, Dominican Republic, Puerto Rico and Lesser Antilles; parts of United States, Mexico, Guatemala, Belize, Honduras, Nicaragua and Costa Rica
Generalized hydrogeological setting	This region includes the low, flat areas along the Atlantic coast and the Gulf of Mexico, associated with the Ouachita tectonic depression. The coastal plains are huge seawards-thickening wedges of unconsolidated sedimentary rocks lying on consolidated limestone and sandstones. The sediments are of fluvial, deltaic and shallow marine origin. The Caribbean island arc (several thousand islands) is a partially submerged cordillera, having a nucleus of igneous rocks overlain by sediments and volcanics. The region receives abundant precipitation. Main physiographic units or geological provinces: a) Atlantic Planes (incl. Florida Peninsula) b) Mexican Gulf Plains (incl. Yucatan Peninsula) c) Caribbean Plains d) Caribbean islands arc Groundwater resources are abundant. Large regional groundwater systems are developed in unconsolidated and (semi-)consolidated sediments (e.g. Coastal lowlands aquifer system and Mississippi River Valley aquifer system). Karst aquifers are frequently found (e.g. Florida and Yucatan aquifer systems). Large islands have combined unconsolidated (alluvial), carbonate and volcanic aquifers.
Adequacy of information accessed on saline groundwater	Quite some information available for the territories of USA and Mexico, but usually without details on depth and lateral extent. Information on saline and brackish groundwater in Central America and the Caribbean region is scarce.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* The region is characterized by extensive occurrence of connate saline and brackish groundwater of mainly marine origin and by seawater intrusion. The latter is a major problem in the Caribbean region, especially on islands with shallow fresh water lenses (such as the Bahamas). *Connate saline groundwater of marine origin (NaCl type,* A1*)* is found in large parts of the USA's Coastal Plain Region: in the Northern Atlantic Coastal Plain Aquifer System, the South-Eastern Coastal Plain Aquifer System, the Texas Coastal Lowlands Aquifer System, the Texas Coastal

	Uplands Aquifer System, the Mississippi Embayment Aquifer System, the Coastal Lowlands Aquifer System, as well as in the Floridan Aquifer System (together denoted as 11). *Seawater intrusion* (genetic type A4) has been prominent in the Biscaine aquifer in Florida (12) (period 1904-1953), but the saline intrusion wedge has stabilized or even reduced since then. Seawater intrusion is also affecting locally the Mexican coastal area along the Gulf of Mexico and many of the Caribbean islands (13). Most of these zones contain also brackish water of different origin, mostly connate or other relict water. In Costa Rica (7), with overflow to groundwater region 1, a zone occurs with brackish groundwater, which has a marine origin (A0). Brackish groundwater in the Mexican territories along the Gulf Coast (Rio Bravo, Golfo Norte and Yucatan regions) (14) have partly an *anthropogenic origin* (resulting from soil salinization due to irrigation, C1) and/or represent *relict brackish groundwater of marine origin* (B1, A2 or A3; mapped as D0).
Current or potential threats of saline groundwater to the interests of society or ecosystems	Given the long sea shore lines, seawater intrusion is a prominent threat, followed by up-coning of connate saline groundwater under poor groundwater management.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	USA and Mexico are seriously contemplating the development and use of brackish groundwater.
Human responses to threats and or opportunities(management)	Interesting example of successful saline groundwater control in the Biscayne aquifer in Florida.
Impact of expected or observed global change	-
Selected references	Conagua, 2007b. Portal on water in México (http://www.conagua.gob.mx/Conagua/Espaniol/TmpContenido.aspx?id=24002a7d-7cf5-4153-adeb-6e36ce1dff13|SISTEMA%20NACIONAL%20DE%20INFORMACIÓN%20DEL%20AGUA|10|0|0|0|0), consulted in October 2008 Dennehy, K.F., 2004. National perspective on saline aquifers, Water Desalination and Reuse Strategies for New Mexico, New Mexico Water Resources Research Institute Jiménez, B., and L. Marín, 2004. El agua en Mexico vista de la Academia, Academia Mexicana de Ciencias Read, H. H. and J. Watson, 1975. *Introduction to Geology, Volume 2: Earth history*, Macmillan, London UNESCO/PHI and OEA, 2007. Sistemas acuíferos transfronterizos en las Americas, Evaluación preliminar US Geological Survey, no date. Ground Water Atlas of the United States, (http://capp.water.usgs.gov/gwa/gwa.html), consulted in October 2008 Weyl, R., 1980. Geology of Central America, 2nd edition, *Beiträge zur regionalen Geologie der Erde*, Gebr. Bornträger, Berlin Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

South America

Global Groundwater Region 6: Andean belt	
Countries included	Almost the total territory of Chile and parts of Venezuela, Colombia, Ecuador, Peru, Bolivia and Argentina.
Generalized hydrogeological setting	This region includes the high-elevated areas of South America belonging to the Andean Mobile Belt. Many wide valleys of tectonic origin and valleys resulted from fluvial erosion. The region is composed of heterogeneous rocks. Frequently, a core of granitic and metamorphic rocks is surrounded or partially covered by folded and fractured sedimentary rocks (marine limestone and continental conglomeratic sandstones). On many locations, volcanic rocks (pyroclastic material and lavas) have been ejected or have flowed out. Large variation in climatic conditions is reflected by an above average rainfall in mountains and arid zones. Main physiographic units or geological provinces: a) Andes b) Altiplano c) Coastal Groundwater resources are variable. Groundwater is typically associated with colluvial aquifers in faulted troughs or basins within mountains. The volcanic zones are very important groundwater sources. High fluoride concentrations are common in these zones. Coastal aquifers occur in structural basins filled with marine and alluvial sediments. These aquifers are prone to seawater intrusions.
Adequacy of information accessed on saline groundwater	The presence in this region of saline groundwater at shallow and intermediate depths (< 500 m deep) so far is only fragmentary described in the publications that could be accessed. Some of the information is provided without mentioning the sources.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture*: In this region, saline groundwater at shallow and intermediate depths (< 500 m deep) is known to be present in the Coastal Province, at a few coastal zones in Northern Colombia and Northern Peru, as well as in the Northern half of Chile. Furthermore, sizeable bodies of saline groundwater are observed as well in the Altiplano. Saline groundwater of *marine origin* is reported to occur in scattered coastal zones in Northern Venezuela (Northern plain of Falcón, West coast of Lake Maracaibo) (15 and 16) and Northern Colombia (Guajira, Antioquia) (17 and 18) The presence is attributed to *seawater intrusion (A4)* caused by strong groundwater level declines in intensely exploited aquifers. Brackish groundwater along the coast of Ecuador (provinces of Esmeraldas, Manabí and Guayas) (19) and Northern Peru (Tumbes-Piura zone) (20) are likely to be of marine origin, but it is not clear whether it is caused by seawater intrusion (A0). In the Colombian Guajira (17), the presence of 'salinas' and the exploitation of their salts indicate that mechanisms other than only seawater intrusion are likely to play a role (*evaporation and/or dissolution of evaporates*). In the North-Chilean part of the Coastal Province, in the arid zone between

	Arica and Antofagasta, there are several large salt flats (Salar de Pintados, Salar Grande, and Salar de Llamara) (21, 22, 23) and numerous smaller ones. They are located mostly between 20 and 100 km from the coast, in closed (endorheic) basins inside the so-called Central Depression. Under and around these salt flats, brackish and saline groundwater is present because of *evaporation* (B1) and perhaps partly by *dissolution of salt from salt crusts* (B2) formed at the surface. Mapped as (B5). *Discharge of surface water and groundwater by evaporation (B1)* is also the main origin of saline and brackish groundwater commonly found in the Southern part of the Altiplano. This mechanism is supported by the Altiplano's dry climate and the absence of surface water drainage. From North to South this zone encompasses large salt flats in Bolivia (Salar de Coipasa, Salar de Uyuni) (24 and 25), Chile (Salar de Atacama) (26)and Argentina (Salinas Grandes, Salar de Arizaro, Salina de Antofalla) (27, 28, 29) and numerous smaller ones (30 to 43). The Salinas Grandes south of Santiago de Estero (44) partly occur in groundwater region 7. Throughout the Andean region there are numerous locations where *thermo-mineral groundwater (B4)* is discharging. In addition, the deeper part of Tertiary-Quaternary sedimentary fills of many montane basins is likely to be brackish or saline, due to evaporation during early stages of the formation of the basins (undrained lake). The local scale of these phenomena prevents them from being depicted on a world map.
Current or potential threats of saline groundwater to the interests of society or ecosystems	Threats are relatively modest and seem mainly related to seawater intrusion (at selected locations along the Pacific coast).
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Not identified.
Human responses to threats and or opportunities(management)	-
Impact of expected or observed global change	Sea level rise may increase seawater intrusion hazards along Pacific coast.
Selected references	Insitituto Geográfico Agostin Codazzi, 1970. Atlas Básico de Colombia, Editorial Andes, Bogotá, Colombia Montes de Oca, I.l, 1997. Geografía y Recursos Naturales de Bolivia, 3ra Edición, Edobol, La Paz, Bolivia Moreno, T., and Wes Gibbons, eds, 2007. *The Geology of Chile*, Geological Society of London, The Geological Society Publishing House, Bath, UK Read, H. H. and J. Watson, 1975. *Introduction to Geology, Volume 2: Earth history*, Macmillan, London Rebouças, A. da C., 1999. Groundwater resources in South America, In: Episodes, Vol.22(3) Sauer, W., 1971. Geologie von Ecuador, *Beiträge zur regionalen Geologie der Erde*, Band 11, Gebrüder Borntraeger, Berlin/Stuttgart Steinmann, G., 1929. *Geologie von Perú*, Carl Winters Universitätsbuchhandlung, Heidelberg UNESCO and Servicio Geológico de Brazil (DNMP/CPRM), 1996. Mapa Hidogeológico de América del Sur

	UNESCO/PHI and OEA, 2007. Sistemas acuíferos transfronterizos en las Americas, Evaluación preliminar US Corps of Engineers, 2001-2005. Water Resources of Latin America and the Caribbean (www.sam.usace.army.mil/en/wra/wra.html), consulted in October 2008 WHYMAP, 2008. Groundwater Resources of the World. Map 1: 25 million. UNESCO/IAH/BGR and associated organizations Zeil, W., 1979. The Andes - A geological review, *Beiträge zur regionalen Geologie der Erde,* Band 13, Gebrüder Borntraeger, Berlin/Stuttgart Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Global Groundwater Region 7: Lowlands of South America	
Countries included	Parts of Venezuela, Colombia, Brazil, Ecuador, Peru, Bolivia, Paraguay, Argentina, Uruguay and Chile
Generalized hydrogeological setting	This region includes the low to moderate elevated, flat areas of South American sedimentary basins, relatively unaffected by tectonic events. Thick sedimentary sequence is composed of consolidated (mainly conglomerates and sandstone) and unconsolidated sediments of alluvial, lacustrine and aeolian origin transported from neighbouring high-elevated areas. The region receives moderate to very high precipitation. Main physiographic units or geological provinces: a) Orinoco basin (Northern Ilanos Basins) b) Amazon basin c) Pantanal and Gran Chaco d) Pampas with Rio de la Plata estuary e) Parana Basin f) Patagonia plains Groundwater resources are abundant. The unconsolidated alluvial sediments, deposited by the major rivers (e.g. aquifers in the Amazon basin and the Puelches Aquifer) and sandstones (e.g. the Guarani aquifer system) form the most important aquifers. Saline water and high concentrations of arsenic and fluoride are common.
Adequacy of information accessed on saline groundwater	Variable degree of information, but most parts of the region – often with very low population densities and low demands for groundwater - have hardly been studied.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* As far as encountered in easily accessible sources of information, brackish and saline groundwater is not common in the Northern half of the region, but it is affecting large parts of lowlands in Paraguay and Argentina (in particular Gran Chaco and Pampas). A very large, more or less continuous zone of brackish groundwater can be observed running from the Paraguayan part of the Gran Chaco all the way South to Eastern Patagonia (45). This water is considered to be predominantly *connate saline groundwater* (A1) originating from the Miocene marine invasion (Mar Enterriano or Mar Paranense, (46). To the West, there is a gradual transition to zones where *recent evaporation* is the more dominant origin of groundwater salinity. The latter is substantiated by the enormous salt flat '*Salinas Grandes'* South of Santiago

	de Estero (B1) and the salt flats further North, along the course of Rio Salado (see region 6) (B5). Simultaneously with the Mar Enterriano a marine transgression invaded the Amazon area as well (Amazonian Sea), but at present the related *connate saline groundwater* is probably located at depths greater than 500 m in this area. *High mineralization* (B2) is also reported for groundwater in the Paleozoic sediments located under the Guaraní aquifer and the lower parts of this aquifer system, but this saline water is likely to be found at great depths only.
Current or potential threats of saline groundwater to the interests of society or ecosystems	In this region, keeping saline groundwater under control is highly important to safeguard groundwater use for various purposes, to maintain a suitable living environment and to support agriculture and ecosystems. Groundwater abstraction is of vital importance for a large percentage of the population.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	-
Human responses to threats and or opportunities(management)	Salinity control is in principle addressed in ongoing groundwater resources management projects, such as the transboundary aquifer projects related to the Guaraní aquifer system (SAG; Bra/Par/Arg/Ur) or the Yrendá- Toba-Tarijeño aquifer system (SATT; Par/Arg/Bol).
Impact of expected or observed global change	Sea level rise may increase seawater intrusion hazards.
Selected references	Insitituto Geográfico Agostin Codazzi, 1970. Atlas Básico de Colombia, Editorial Andes, Bogotá, Colombia Ministry of Environment, Secretariat of Water Resources, Brasilia, 2006a. Plano Nacional de Recursos Hídricos, Executive synthesis (in English) Ministry of Environment, Secretariat of Water Resources, Brasilia, 2006b. Plano Nacional de Recursos Hídricos, Cap.10: Situação actual das Águas do Brazil Montaño, X., Gagliardi, J., S. and M. Montaño, 2006. Recursos hídricos subterráneas del Uruguay, *Boletín Geológico y Minero*, Vol. 117(1), IGME, España Montes de Oca, I., 1997. *Geografía y Recursos Naturales de Bolivia*, 3ra Edición, Edobol, La Paz, Bolivia Moreno, T., and Wes Gibbons, eds, 2007. *The Geology of Chile*, Geological Society of London, The Geological Society Publishing House, Bath, UK Read, H. H. and J. Watson, 1975. *Introduction to Geology, Volume 2: Earth history*, Macmillan, London Rebouças, A. da C., 1999. Groundwater resources in South America, *Episodes*, Vol. 22(3) Sauer, W., 1971. Geologie von Ecuador, *Beiträge zur regionalen Geologie der Erde*, Band 11, Gebrüder Borntraeger, Berlin/Stuttgart Steinmann, G., 1929. *Geologie von Perú* Carl Winters Universitätsbuchhandlung, Heidelberg UNESCO and Servicio Geológico de Brazil (DNMP/CPRM), 1996. Mapa Hidrogeológico de América del Sur UNESCO/PHI and OEA, 2007. Sistemas acuíferos transfronterizos en las Americas. Evaluación preliminar US Corps of Engineers, 2001-2005. Water Resources of Latin America and the Caribbean (www.sam.usace.army.mil/en/wra/wra.html), consulted in October 2008 WHYMAP, 2008. Groundwater Resources of the World. Map 1: 25 million. UNESCO/IAH/BGR and associated organizations

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Global Groundwater Region 8: Guyana Shield	
Countries included	Guyana, Surinam, French Guyana and parts of Venezuela, Colombia and Brazil
Generalized hydrogeological setting	This region includes the moderate elevated, flat topped, Guyana Shield in North-Eastern part of the continent. Crystalline rocks cover almost whole area. The region has a warm and humid climate with annual rainfall in the range of 1000-2000 mm. Groundwater resources are restricted by geological conditions, except for relatively narrow sedimentary zones along the coast. Based on these different hydrogeological conditions, the region is subdivided into two groundwater provinces: a) Guyana Shield province: mainly Precambrian igneous and metamorphic rocks with low potential for storing and transmitting groundwater. b) Guyana Coastal province: deltaic multilayer sandy aquifer systems in the coastal lowlands. They are the main aquifers of the region.
Adequacy of information accessed on saline groundwater	The coastal zones of Guyana and Surinam have been studied to some extent, for other parts of the region, almost no relevant information has been encountered.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* Saline groundwater at shallow and intermediate depths (< 500 m below ground level) has been observed in the Coastal Province. Groundwater obtained from granites and gneisses in the Shield Province may be saline and brackish, but information sources are contradictory in this respect. Saline groundwater originating from *seawater intrusion* (A4) is present in the Northwestern coastal zone of Guyana (48). Seawater intrusion is also a risk elsewhere along the Atlantic coast, under conditions of groundwater exploitation. The upper aquifer bed of the coastal aquifer system is reported to contain quality water in parts of Guyana.
Current or potential threats of saline groundwater to the interests of society or ecosystems	Main threats are the seawater intrusion hazards along the Atlantic coast, in response to locally intensive groundwater abstraction.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	
Human responses to threats and or opportunities(management)	-
Impact of expected or observed global change	Sea level rise may increase seawater intrusion hazards.
Selected references	Ministry of Environment, Secretariat of Water Resources, Brazilia, 2006a. Plano

	Nacional de Recursos Hídricos, Executive synthesis (in English) Ministry of Environment, Secretariat of Water Resources, Brazilia, 2006b. Plano Nacional de Recursos Hídricos, Cap.10: Situação atual das Águas do Brazil Read, H. H. and J. Watson, 1975. *Introduction to Geology, Volume 2: Earth history*, Macmillan, London Rebouças, A. da C., 1999. Groundwater resources in South America, *Episodes*, Vol.22(3) UNESCO and Servicio Geológico de Brazil (DNMP/CPRM), 1996. Mapa Hidrogeológico de América del Sur UNESCO/PHI and OEA, 2007. Sistemas acuíferos transfronterizos en las Americas, Evaluación preliminar US Corps of Engineers, 2001-2005. Water Resources of Latin America and the Caribbean (www.sam.usace.army.mil/en/wra/wra.html), consulted at October 2008 WHYMAP, 2008. Groundwater Resources of the World. Map 1: 25 million. UNESCO/IAH/BGR and associated organizations WHYMAP, 2008. Groundwater Resources of the World. Map 1: 25 million. UNESCO/IAH/BGR and associated organizations Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Global Groundwater Region 9: Brazilian Shield and Associated Basins	
Countries included	Parts of Brazil and Bolivia
Generalized hydrogeological setting	This region includes the low to moderate elevated, predominantly flat Brazilian Shield with associated younger sedimentary basins. The Brazilian Shield is mainly composed of crystalline rocks. The associated basins contain a sequence of sandstone, volcanic rocks and unconsolidated sediments. Region receives high precipitation. Main physiographic units or geological provinces: a) Brazilian Shield (North, Central, East and South) b) Parnaiba Basin c) Sao Francisco Basin d) Brazilian coastal Groundwater resources are variable. Groundwater in the crystalline rocks is restricted to local pockets of weathered or fractured zones or to shallow layers of sediments. In the sedimentary basins, both sandstones and unconsolidated sediments can form large aquifers. The volcanic areas (predominantly basalts) have limited groundwater potential.
Adequacy of information accessed on saline groundwater	Limited information.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* One major zone of saline groundwater is known to occur in the North-Eastern part of the Brazilian Shield province (49). It roughly coincides with the most arid part of Brazil and hence the origin of salinity is assumed to be mainly related to *evaporation* (B1). The aquifers of the coastal province are exposed to the hazard of *seawater intrusion*, but no information has been found so far to map presently affected zones.
Current or potential threats of saline groundwater to the	

interests of society or ecosystems	
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	
Human responses to threats and or opportunities(management)	-
Impact of expected or observed global change	Sea level rise may increase seawater intrusion hazards.
Selected references	Ministry of Environment, Secretariat of Water Resources, Brazilia, 2006a. Plano Nacional de Recursos Hídricos, Executive synthesis (in English) Ministry of Environment, Secretariat of Water Resources, Brazilia, 2006b. Plano Nacional de Recursos Hídricos, Cap.10: Situação atual das Águas do Brazil. Montes de Oca, I., 1997. *Geografía y Recursos Naturales de Bolivia*, 3ra Edición, Edobol, La Paz, Bolivia. Read, H. H. and J. Watson, 1975. *Introduction to Geology, Volume 2: Earth history*, Macmillan, London Rebouças, Aldo da C., 1999. Groundwater resources in South America, In: *Episodes*, Vol.22(3) UNESCO and Servicio Geológico de Brazil (DNMP/CPRM), 1996. Mapa Hidrogeológico de América del Sur. UNESCO/PHI and OEA, 2007. Sistemas acuíferos transfronterizos en las Americas, Evaluación preliminar. US Corps of Engineers, 2001-2005. Water Resources of Latin America and the Caribbean (www.sam.usace.army.mil/en/wra/wra.html) WHYMAP, 2008. Groundwater Resources of the World. Map 1: 25 million. UNESCO/IAH/BGR and associated organizations Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Europe

Global Groundwater Region 10: Baltic and Celtic shield	
Countries included	Iceland, Norway, Sweden, Finland, Ireland and parts of UK (N.Ireland, Scotland, Wales), France (Bretagne), Estonia (North) and Russia (Karelia)
Generalized hydrogeological setting	This region includes the low to moderate elevated, predominantly flat areas of Baltic Shield and Ireland-Scotland Platform. Included are also higher elevated areas of Norwegian Caledonides, Iceland, and Massif Armoricain which have more pronounced relief. The Baltic Shield, the Scotland Platform and Massif Armoricain are mainly composed of crystalline rocks. The Ireland Platform is composed of sedimentary rocks, while Iceland is built almost exclusively of young volcanic rocks, predominantly basalts. Region receives medium to high precipitation. Main physiographic units or geological provinces: a) Baltic Shield

	b) Norwegian Caledonides c) Island of Iceland d) Ireland-Scotland Platform e) Massif Armoricain Groundwater resources are limited. Groundwater in crystalline rocks is restricted to local pockets of weathered or fractured hard rocks. The only widespread aquifers with inter-granular permeability are found in the Quaternary deposits (glacio-fluvial deposits). Local karst aquifers occur in Ireland (e.g. the Waulsortian aquifer). The recent volcanoclastics are highly permeable and can form local aquifers in Iceland.
Adequacy of information accessed on saline groundwater	Limited information, mainly on Sweden, Ireland and Iceland. Lack of information suggests that saline groundwater is not an issue in Norway, Finland, Karelia, Scotland, Wales and Bretagne.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* For relatively shallow depths (< 500 m) no reports on large bodies of saline groundwater have been encountered so far. This is consistent with what could be expected based on the predominant geological setting. *Relict saline groundwater* of marine origin can be found in a large continuous zone in central Sweden and along the present Baltic Sea coastline in Sweden and Finland. This saline water is not connate, but originates from two postglacial transgressions of the Baltic Sea: the Yoldia Sea (about 7700 BC; brackish) and the Litorina Sea (about 5000 BC; saline) (50). Hence, the saline groundwater corresponds to genetic type A2. The area of occurrence is large, but due to the volume of saline groundwater relatively modest. *Seawater intrusion* (A4) is reported to occur into the Cretaceous Alnarps aquifer (limestone) in Scania (51), Southern Sweden, but the salt water body seems to be small. Elsewhere along the long coastlines, there may be other cases of seawater intrusion e.g. in Ireland (52), but geological conditions suggest only locally and/or slightly affected groundwater systems. *Highly saline brines* are reported for the Reykjavic peninsula in Iceland (53). These brines are attributed to “infiltration of seawater” into geothermal systems (B4), but this mechanism does not explain groundwater salinity in excess of seawater salinity. A zone of salt water related to *tectonics* and the former Permian Zechstein Sea also occurs at the border with region eleven (54) (B2). See further on for more information.
Current or potential threats of saline groundwater to the interests of society or ecosystems	Some of the papers report saline groundwater as a threat to drinking water supply. Certainly, the presence of saline groundwater has to be taken into account when preparing for new wells. Overall, the region seems to be affected only very slightly by groundwater salinity.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Not mentioned in consulted papers.

Human responses to threats and or opportunities(management)	As far as reported, mainly of anticipating nature: studies on occurrence of saline groundwater and on their dynamic behaviour. Closure of critically located wells is mentioned a few times.
Impact of expected or observed global change	Not mentioned in consulted papers. A few relevant zones should receive attention, such as volcanic coastal zones (Iceland, Ireland) and sedimentary inlays in coastal zones (Southern Sweden)
Selected references	Science Institute, University of Iceland, www.raunvis.hi.is, consulted at October 2008 SWIM, 1999, Proceedings of the 15th SWIM meeting in Ghent, Belgium, 1998, *Natuurwetenschappelijk Tijdschrift*, Vol. 79 SWIM, xxx, Proceedings of the 14th SWIM meeting in xxx SWIM, xxx, Proceedings of the 7th SWIM meeting in xxx UK Groundwater Forum, www.groundwateruk.org/archive/sea_water_intrusion.pdf, consulted at October 2008

Global Groundwater Region 11: Lowlands of Europe	
Countries included	Denmark, The Netherlands, Belgium, Luxemburg, Lithuania, Latvia, Belarus, Moldova and parts of UK (England), France, Germany, Poland, Estonia, Russian Federation, Ukraine, Romania, Bulgaria, Kazakhstan and Turkmenistan
Generalized hydrogeological setting	This region includes the low elevated, flat areas of European sedimentary basins. The higher elevated areas, associated with the Uralian Orogenic Belt, are included in this region as an administrative boundary between Europe and Asia. Thick sedimentary sequence is composed of consolidated and unconsolidated sediments of marine, aeolian and alluvial and origin. Region receives medium to high precipitation. Main physiographic units or geological provinces: a) Anglo & Paris Basin b) Aquitaine Basin c) London & Brabant Platform d) Dutch Basin e) Northwest German Basin f) German-Polish Basin g) Russian Platform h) Ural Mountains Groundwater resources are abundant. The unconsolidated sediments form the most important aquifers in the deltas of main rivers (e.g. in the Netherlands). Glacial and aeolian aquifers are of local importance. In south-western and northern basins, limestone aquifers are found (e.g. the Chalk Aquifer). The central and eastern parts of the regions have also extensive sandstone aquifers. The Ural Mountains, composed of crystalline rocks have limited groundwater resources. All coastal aquifers are prone to saline intrusion.
Adequacy of information accessed on saline groundwater	There is a large amount of information, in particular on seawater intrusion in the North Sea region. However, almost no information has been found on the situation in the Russian territory and the Black Sea and Caspian Sea zones.

Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* shallow saline groundwater (< 500 m deep) is present prominently and in considerable volumes throughout the region, particularly in the coastal zones. *Connate saline groundwater* (A1) is very common in more or less continuous belts until hundreds of kilometres wide along the Southern shores of the North Sea, the Baltic Sea and associated gulfs. Huge amounts of connate saline water are trapped in sea-ward dipping marine geological formations or have migrated to overlying terrestrial formations. Saline groundwater as a relict of *marine transgression* (A2)or *flooding by the sea* (A3) may be present in the same coastal zones where connate seawater and recent lateral seawater intrusion are observed. However, their volume is very limited in this region. *Seawater intrusion* is a threat almost anywhere along the sea coast, since the coastlines are mostly underlain by high-capacity aquifers hydraulically connected to the sea. Especially the coastal aquifers of Belgium and The Netherlands (55) have been the subject of many seawater intrusion studies, which suggests the local relevance of this phenomenon. The 'seawater intrusion tongues' are dynamic but represent saline groundwater bodies (A4) of modest dimensions only, compared to the bodies of connate saline groundwater. Several rivers with extremely low hydraulic gradient bring the seawater intrusion risk to aquifer locations inland. *Dissolution of salt* forms another source of saline groundwater in the region (B2). This is particularly so in a zone of salt tectonics related to the former Permian Zechstein Sea, extending from Eastern England (54) to Northern Poland (56). Especially in the North-Eastern part of The Netherlands and Northern Germany, diapirs of Permian salts penetrate overlaying younger geological formations and by dissolution, they locally have turned originally fresh aquifers into saline ones. A second important zone of highly mineralized groundwater due to dissolution is found in West Russia, where Permian salt domes the city of Perm (57). In the Severnaya Dvina artesian basin in NW Russia (58), where Lower-Permian dolomite-gypsum and anhydrite strata have contributed to groundwater mineralization up to 10 grams per litre. Extensive bodies of brackish and saline groundwater, probably of *mixed origin* (D0) are found along the Northern shores of the Black Sea (Ukraine; Moldavia) (59) and the Caspian Sea (parts of Russian Federation, Kazakhstan and Turkmenistan) (60 and 61). Close to both seas, connate saline groundwater and intruded seawater may be present (genetic components A1 and A4) (62), but particularly in the Caspian Sea region saline groundwater may be expected as a result of climatic features (B1 and C1), mapped as D0. The Northern zone of the Aral sea area (62) is located in the Southern part of this groundwater region. Aral Seawater has salinized due to high aridity (B1), decrease inflow of freshwater from upstream river basins (water allocated to large-scale irrigation systems) and uploading from agricultural leachates (C1/C2).
Current or potential threats of saline groundwater to the interests of society or	In this region, keeping saline groundwater under control is highly important to safeguard groundwater use for various purposes, to maintain a suitable living environment and to support agriculture and ecosystems. A large percentage of the population lives in areas near the coast, sensitive for

ecosystems	groundwater salinization.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Not mentioned in consulted papers.
Human responses to threats and or opportunities(management)	As far as reported, mainly of anticipating nature: studies on occurrence of saline groundwater; monitoring groundwater salinity at different depths and simulation of the dynamic behaviour of fresh, brackish and saline groundwater. On a practical level, the acquired knowledge is used for planning and protection of groundwater resources, well fields and ecosystems.
Impact of expected or observed global change	Obviously, the region is sensitive for rising seawater levels, which may jeopardize fresh groundwater resources in the coastal zones, unless appropriate measures are taken.
Selected references	Börner, K., 2004. Evaporite basins with emphasis on the Permian Zechstein, Oberseminar 2003/2004, Technischer Universität, Bergakademie Freiberg Read, H. H. and J. Watson, 1975. *Introduction to Geology, Volume 2: Earth history*, Macmillan, London SWIM, proceedings of SWIM meetings 1 to 19, http://swim-site.org, consulted at October 2008 Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Global Groundwater Region 12: Mountains of Central and Southern Europe	
Countries included	Czech Republic, Slovakia, Switzerland, Austria, Hungary, Portugal, Spain, Andorra, Monaco, Italy, San Marino, Malta, Slovenia, Croatia, Bosnia & Herzegovina, Serbia & Montenegro, Albania, Macedonia, Greece, Cyprus and parts of France, Germany, Poland, Ukraine, Romania and Bulgaria
Generalized hydrogeological setting	This region includes the high-elevated areas of Europe belonging to the Hercynian and Alpine Orogenic Belt. Also included are low to medium elevated sedimentary basins associated with these tectonic structures. The folded areas have complex lithology with altering crystalline, volcanic and sedimentary rocks. Western sedimentary basins contain thick sequence of predominately carboniferous rocks. The eastern basins are covered with thick layers of unconsolidated sediments. Large variations in climate are reflected by an above average rainfall in mountains and dry zones in the lowlands. Main physiographic units or geological provinces: a) Iberian Massifs (a.o. the Hesperian Massif) and adjusted coastal plains b) Tajo- Duero Basin c) Pyrenees d) Massif Central e) Jura, Vosges and Ardennes f) Southern German Basins g) Alps h) Po Basin i) Apennines

	j) Bohemian massifs k) Pannonian Basin l) Carpathian Mountains m) Dinaric Alps Groundwater resources are variable. Groundwater in crystalline rocks is restricted to local pockets of weathered or fractured hard rocks. Alluvial and colluvial fill of relative flat areas form local aquifers in the mountains. In the sedimentary basins, limestone, sandstones, and unconsolidated sediments can form large interconnected aquifer systems (e.g. Po Plain aquifers and Hungarian Plain aquifers).
Adequacy of information accessed on saline groundwater	Large amount of information, in particular on seawater intrusion. In this respect, it is probably the best-documented area in the world, together with Global Groundwater Region 11.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* shallow saline groundwater (< 500 m deep) is present prominently in the coastal zones of the region, particularly in the form of active 'seawater intrusion wedges or tongues'. Elsewhere, mineralized groundwater is found, but apparently in a rather fragmented mode of occurrence. *Connate saline groundwater* (A1) is likely to be present as well in the region, but references to it are rare in consulted literature. Saline and brackish groundwater due to *seawater intrusion* (A4) is common along the entire coast, but due to different geology and topography, the picture is more variable than in regions of large sedimentary basins (such as Global Groundwater Region 11). In this region, seawater intrusion is manifest in many scattered small pockets of productive detritic aquifer systems (such as deltas) and more regionally in coastal parts of karstic aquifers (63 to 85). In between there may be no significant intrusions due to low-permeability rocks along the coast, separating fault systems or strong sea-ward hydraulic gradients. Karstic aquifers are present in all countries bordering the Mediterranean Sea, but seawater intrusion is especially strongly developed in the Dinaric karst of Croatia and neighbouring countries. More than in other regions of Europe, this region is threatened by steadily more encroaching seawater, triggered by intensive groundwater abstraction. The region includes many sites where *thermo-mineral groundwater* (B4) is encountered and exploited (spas). So far, they have not been linked with medium- to large-sized saline groundwater bodies. In addition, *irrigation* is significant in the Southern part of the region. It will already have made impact on groundwater mineralization in the corresponding zones (C1), and certainly represents a risk to groundwater quality in the future.
Current or potential threats of saline groundwater to the interests of society or ecosystems	In this region, keeping saline groundwater under control is highly important to safeguard groundwater use for various purposes and to support agriculture and ecosystems. Water scarcity in the Southern part of the region and resulting intensive groundwater abstraction make it very difficult to control further ingress of saline water into the aquifers.
Current or potential benefits (opportunities) of	Not mentioned in consulted papers.

saline groundwater to the interests of society or ecosystems	
Human responses to threats and or opportunities(management)	As far as reported, mainly of anticipating nature: studies on occurrence of saline groundwater; monitoring groundwater salinity at different depths and simulation of the dynamic behaviour of fresh, brackish and saline groundwater. On a practical level, the acquired knowledge is used for planning and protecting groundwater resources, well fields and ecosystems.
Impact of expected or observed global change	Obviously, the region is very sensitive for rising seawater levels, which may jeopardize fresh groundwater resources in the coastal zones, unless appropriate measures are taken. This is particularly true for the karstic coastal aquifers.
Selected references	Lopez-Geta, J.A., Gomez, J., Orden, J., Ramos, G., and L. Rodriguez. (eds.), 2003. Coastal Aquifers Intrusion Technology: Mediterranean Countries, IGME, Madrid, Spain SWIM, proceedings of SWIM meetings 1 to 19, http://swim-site.org, consulted at October 2008

Africa

Global Groundwater Region 13: Atlas mountains	
Countries included	Parts of Morocco, Algeria, Tunisia
Generalized hydrogeological setting	This region includes the elevated areas of the Atlas Mountains, created during the Alpine orogenesis in Northwestern Africa. The Northern part is composed of folded sedimentary rocks (mainly limestone). In the Southern part, basement crystalline rocks are covered by shallow marine and alluvial sediments. Precipitation shows large spatial and temporal variation. The Southern areas are subject to desert influences. The main geological / morphological areas are: a) Northern Atlas mountain range (Anti, High, Middle and Tell Atlas) b) El-Shatout depression c) Saharan Atlas mountains in the South Groundwater resources are limited to alluvial sediments in the mountains, karstic aquifers in the Northern part and shallow aquifers at the North and North-West coast.
Adequacy of information accessed on saline groundwater	Information with the exception of Morocco is very scant and of various sources.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* Most saline water in this region is to be found at the coast and is of marine origin. In the east and southeast of the region, evaporation plays an imported role in the occurrence of saline/brackish groundwater. At Atlantic coast large aquifers exists (Cretaceous and Palaeocene aquifers in Southern Morocco) which contain *fossil* water that becomes increasingly more mineralized with depth. Salinity here reaches from 2 to 10 g/l at depths from 400 to 1600 m (A1). Due to intensive pumping of the Atlantic and Mediterranean coastal aquifers, salt water up-coning is a serious problem (Agadir, Rabat) (86, 87). Along the Mediterranean coast, shallow aquifers are especially prone to seawater *intrusion* in case of groundwater pumping

	for intensive irrigation (A4) (88, 89). In the Atlas mountains local aquifers exist, many of which contain brackish water due to *dissolution* of salt-bearing rock (B2) and/or *evaporation* (B1). These are mainly shallow aquifers (90). Some *chotts/sebkhets* are connected with shallow aquifers and form a complex mixture of fresh, brackish and saline water (Chotts ech Chergui and el Hodna) A *sebkhet* (or sebkha, sabkhat) (91) is a large, shallow depression that holds water seasonally, though sometimes for over a year. Unlike sebkhets, chotts are irregularly flooded and may not be flooded every year (B1). Along the coast with high groundwater abstraction e.g. along the Mediterranean and Atlantic coasts salt water up-coning occurs (Annaba and Oran area in Algeria.
Current or potential threats of saline groundwater to the interests of society or ecosystems	Diminishing of drinking water and irrigation water availability.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	At some saline flats/lakes, salts are being mined.
Human responses to threats and or opportunities(management)	Better irrigation practices, more salt tolerant crops, more efficient use of the scarce resources, and desalination of seawater.
Impact of expected or observed global change	
Selected references	Burgis, M.J.and J.J. Symoens, Eds, 1987. African wetlands and shallow water bodies, Paris, France, Editions de I'Orstom Ramsar Convention on Wetlands, http://www.ramsar.org/wn/w.n.tunisia_19.htm, and http://www.ramsar.org/wn/w.n.algeria_16.htm consulted on September 2008 http://www.water.gov.ma/01presentation/ressources.htm, consulted at October 2008 Royaume du Maroc, Secrétariat d'Etat chargé de l'Eau, UN Water-Africa, 2004. Rapport National 2004 sur les Ressources en Eau au Maroc, Mokhtar Bzioui, Novembre 2004 UN Water-Africa, 2005. Rapport Sous Regional sur la Mise en Valeur des Ressources en Eau en Afrique du Nord, Mokhtar Bzioui, Mars 2005 UNESCO-IHP, 2002. Proceedings of the International Workshop, Tripoli, Libya, 2-4 June 2002, IHP-VI, Series on Groundwater No. 8

Global Groundwater Region 14: Saharan basins	
Countries included	Morocco, Algeria, Tunisia, Libya, Egypt, Sudan, Western Sahara, Mauretania, Gambia, Guinea, Senegal, Mali, Niger, Chad
Generalized hydrogeological setting	This region includes the North African Craton. It comprises a Precambrian basement, unconformably overlain by a thick sequence of continental and marine sediments (clastic sediments covered by carbonates), structured into

	a number of low to medium elevated flat basins separated by higher elevated zones. The flat areas are covered by aeolian sand and locally by alluvial deposits. The region has an arid climate. Main physiographic units or geological provinces: a) Tindoef Basin b) Grand Erg/Ahnet Basin c) Trias /Ghadamedes Basin d) Hamra Basin e) Sirte Basin f) Erdis/Kufra Basin (Nubian sandstone) g) Dakhla Basin (Nubian sandstone) h) Nile valley and delta i) Senegal-Mauritanian Basin j) Regubiat High k) Taoudeni Basin l) Hoggar High m) Iullemeden Basin n) Chad Basin o) Tibesti (Quadai) Mountains p) Ennedi-Darfour Uplift q) Sudan interior basins (Nubian sandstone) Groundwater resources are variable. Groundwater in crystalline rocks is restricted to local pockets of weathered or fractured zones or to shallow layers of fluvial sediments. In the sedimentary basins sandstone and limestone layers form important regional aquifer systems. Some of these aquifers are deep and receive no modern recharge (e.g. The Nubian Sandstone Aquifer). Other systems are recharged in the river valleys (e.g. Iullemeden Aquifer System). Large alluvial aquifers developed along the river Nile and in its delta.
Adequacy of information accessed on saline groundwater	
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* In this region, a large part of the saline groundwater has its origin connected to climatologic factors (high evaporation and scant rainfall). Along the Atlantic and Mediterranean coasts salt water intrusion is a main factor and in the deeper and older aquifers relict marine water is the main source (92, 93, 94, 95) (A4). Two deep aquifer systems with little or no recharge underlie the greater part of the Sahara: the North Western Sahara Aquifer System (NWSAS) (96) and the Nubian Sandstone Aquifer System (NSAS) (97). The Northern confined part of the NSAS contains saline water of *connate* origin at relatively shallow depth (A1). In the Niger basin, the southern part of the Tin Séririne-Irhazer and Iullemeden aquifer (98) contain brackish to saline fossil water with TDS up to 30 g/l. There are more 'stacked' aquifers in the area with increasing mineralization with depth and to the South (A1). The deep depression near the coast in Northern Egypt facilitates also lateral *intrusion* of seawater (A4). In the El Natrun and Qattara depressions in Egypt, salt is accumulating by *evaporation* of discharging groundwater (99 and 100) (B1). In the Chotts area in Algeria and Tunesia, saline mudflat deposits can be found due to

	either evaporation of sporadic rainfall or evaporation of artesian groundwater from the NWSAS (B1/B2) (101 and 102) (B5). Saline lakes exist in the Zellaf dunes at the Eastern extend of the Ubari Sand Sea, e.g. lake Gabraoun (103) (B1). In the Lake Chad basin, the upper aquifer (0-50 m) has saline water near the lake border due to *evaporation* (B1) (104). Shallow salt deposits are to be found in the Fezzan area in the South of Libya (paleolake Megafezzan, 130,000 km^2) (B1) (105).
Current or potential threats of saline groundwater to the interests of society or ecosystems	In the Siwa oasis in Northern Egypt, increasing deep fresh groundwater abstraction may draw saline water into the fresh aquifer. By over-abstraction of groundwater in the Chott-area, the drop in water table enables the salt crust to dissolve and descend into the aquifer.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	
Human responses to threats and or opportunities(management)	
Impact of expected or observed global change	
Selected references	International Centre for Biosaline Agriculture, 2004. Harnessing Salty Water to Enhance Sustainable Livelihoods of the Rural Poor in Egypt International Centre for Biosaline Agriculture, 2004. Harnessing Salty Water to Enhance Sustainable Livelihoods of the Rural Poor in Tunisia http://uk.geocities.com/morris.drake@btinternet.com/megafezzan.htm, consulted in August 2008 http://uk.geocities.com/morris.drake@btinternet.com/chottmega.htm, consulted in June 2008 Observatoire du Sahara et du Sahel (OSS), USGS/IAEA, 2007. GEF-IW:LEARN, Consulted Management of a Shared Resource Case of North Western Sahara Aquifer System, Groundwater Study (http://www.iwlearn.net/abt_iwlearn/pns/learning/groundwater/latrech_nwsas.ppt#556, consulted August 2008 UNESCO-IHP, 2002. Managing Shared Aquifer Resources in Africa; Proceedings of the International Workshop Tripoli, Libya, 2-4 june 2002, IHP-VI, Series on Groundwater No. 8 Sherif, M.M. and V.P. Singh, 2002. Effect of Groundwater Pumping on Seawater Intrusion in Coastal Aquifers, *Agricultural Sciences*, Vol. 7(2), pp. 61-67 Zektser, I.S. and L.G. Everett, 2004. Groundwater Resources of the World and their Use, UNESCO-IHP, IHP-VI, Series on Groundwater, No. 6

Global Groundwater Region 15: West African basements	
Countries included	Mauretania, Mali, Guinea, Sierra Leone, Liberia, Burkina Faso, Ghana, Togo, Benin, Nigeria, Cameroon, Central African Republic, Equatorial Guinea, Gabon, Republic of Congo, Democratic Republic of Congo, Angola, Namibia, South Africa.
Generalized	This region includes low to moderate elevated, flat areas of the West

hydrogeological setting	African Shield and sedimentary basins associated with large rivers. Narrow coastal strip containing unconsolidated sediments is also included. The Shield areas are dominated by outcropping crystalline Basement rocks. Region has a humid climate in the Northern parts along the coast and a dry climate in the South and the Northern strip along the Sahara. <u>Main physiographic units or geological provinces:</u> a) Eburneen Massif b) Volta Basin c) Niger Delta d) Nigerian Massif e) West Congo Precambrian Belt f) Damer Belt Some areas have high fluoride concentrations. Deltas of large rivers (Volta, Niger) have more favourable groundwater conditions. High arsenic concentrations are found locally.
Adequacy of information accessed on saline groundwater	
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* Saline groundwater in this region has various sources and is mostly widely scattered due to great climate differences. In the coastal areas intrusion and connate marine groundwater can be encountered while in the drier inland areas of the basement relict and modern evaporative water is the main source. In Northern Ghana TDS in groundwater reaches 1500 mg/l. The intermediate aquifer in the Paleozoic sedimentary aquifer contains mostly *connate* saline water (A1) (106). In the Gabon coastal basin, mineralisation increases with depth up to 5 g/l at 500 m depth in Libreville (A1,A4) (107). In the Benue-Trough in Nigeria saline groundwater and brines are to be found (D0). In the Niger Delta (108), fresh groundwater is overlain by saline groundwater. Along the Namibian coast saline water intrusion occurs in a strip from 10 to 40 km wide in the North and up to even 100 km wide in the South (A0) (109). The coastal aquifers in Togo, Benin, Ghana and Nigeria suffer from saltwater *up-coning* of paleo-seawater and *intrusion* due to high groundwater abstraction rates (A4). (104 - 110) In Northwestern Burkina Faso brackish groundwater has been encountered (2700 µS/cm, D0). (111)
Current or potential threats of saline groundwater to the interests of society or ecosystems	In Namibia (saline) groundwater is in many places the only local source for water (since rainfall is very scarce and evaporation very high). This impedes development in those areas. The coastal aquifers of e.g. Ghana and Nigeria are prone to seawater intrusion.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	The brines in the Benue-Trough (Nigeria) are mined for salt production.
Human responses to threats and or opportunities(management)	

Impact of expected or observed global change	
Selected references	Abam, T. K. S., 2001. Regional hydrological research perspectives in the Niger Delta, *Hydrological Sciences-Journal-des Sciences Hydrologiques*, Vol. 46(1) British Geological Survey and WaterAid, 2001. Groundwater Quality: Ghana Christelis, Greg and Wilhelm Struckmeier. Groundwater in Namibia, an explanation to the Hydrogeological Map. December 2001 Faye, S., Maloszewski, P., Stichler, W., Trimborn, P., Cisse´ Faye, S. and C.B. Gaye, 2005. Groundwater salinization in the Saloum (Senegal) delta aquifer: minor elements and isotopic indicators, *Science of the Total Environment*, Vol. 343, pp. 243- 259 Ministry of Agriculture, Water and Rural Development, Ministry of Mines and Energy, 2001. Groundwater in Namibia, an explanation to the Hydrogeological Map. Eds Christelis, G., and W. Struckmeier Tijani, M.N. and E.P. Loehnert, 2004. Exploitation and Traditional Processing techniques of brine salt in parts of the Benue-Trough, Nigeria, *International Journal of Mineral Processing*, Vol. 74 UNESCO-IHP, 2002. Managing Shared Aquifer Resources in Africa; Proceedings of the International Workshop Tripoli, Libya, 2-4 June 2002, IHP-VI, Series on Groundwater No. 8 Zektser, I.S. and L.G. Everett, 2004. Groundwater Resources of the World and their Use, UNESCO-IHP, IHP-VI, Series on Groundwater No. 6

Global Groundwater Region 16: Sub-Saharan basins	
Countries included	Republic of Congo, Democratic Republic of Congo, Angola, Zambia, Zimbabwe, Botswana, South Africa, Mozambique.
Generalized hydrogeological setting	This region includes large inland depressions in basement rocks of Central and Southern Africa that have been filled by sediments of various origins. The sedimentary areas are moderate elevated and have flat relief. Topographical high of crystalline rocks, which separate two Southern basins, is included in this region. Region has a humid climate in the Northern parts and a dry climate in the South. Groundwater resources are abundant. a) Congo basin b) Kalahari-Ethosha Basin c) Kalahari Precambrian Belt (Western part) d) Karoo Basin e) Cape Fold Belt f) Coastal Basins of Mozambique Large regional aquifers are found in unconsolidated sediments (e.g. in Congo basin) and fractured sandstones (e.g. Karoo Aquifer system). Limestone and dolomite layers (e.g. Katanga System) form local aquifers. Shales and crystalline rocks are poor aquifers. Some of the aquifers receive limited modern recharge.
Adequacy of information accessed on saline groundwater	
Main occurrences, origin and dimensions of shallow	*General picture:* The dryer parts in the south of the region have mostly brackish to saline groundwater as a result of low precipitation and high

saline groundwater	evaporation. Along the coast of Mozambique most places suffer from seawater intrusion (A4) (112). In Eastern Caprivi (Namibia) (113) (B1) the upper aquifer contains brackish or salt groundwater. Also a large part of the water in the shallow unconfined aquifers in the Etosha Pan (114) (B5) has high salinity. Some of the deeper aquifers in the Cuvelai area are under artesian pressure and renders brackish groundwater (TDS up to 6700 mg/l). The groundwater salinity in these areas is of B1/B2 origin. Due to high evaporation, low rainfall and no runoff the water in the Southwestern part of the Stampriet Artesian Basin is mostly of poor quality (B1) (115). In North central Namibia there is shallow saline groundwater (B2) (116). In the Kalahari-Karoo aquifer (117) (D0) the water quality is very poor like in the so called Salt Block at the borders of Namibia, Botswana and South Africa. Much of Botswana has brackish to saline groundwater (B1) (118). The Okavango delta has groundwater with high salinity especially outside the delta proper with chloride content of 3000-30000 mg/l (B5) (119). The Southern lowlands of Mozambique (120) have for the most part brackish to saline groundwater (in some areas TDS up to 45g /l). West of Beira in the Chire-Urema Graben, over a North-south distance of 450 km, brackish to saline water is found (B1) (121). Possibly part of the salinity in this graben is explained by the presence of connate water (A1).
Current or potential threats of saline groundwater to the interests of society or ecosystems	In Namibia the deeper and over-pumped wells can attribute to up-coning of deeper more saline water while some deeper wells are possible drilled past the upper freshwater layer causing upward migration of saline groundwater
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	
Human responses to threats and or opportunities(management)	
Impact of expected or observed global change	
Selected references	Bauer, P., Helda, R.J. and S. Zimmermann, 2006. Coupled flow and salinity transport modelling in semi-arid environments: The Shashe River Valley, Botswana, *Journal of Hydrology*, Vol. 316, pp.163–183 British Geological Survey and WaterAid, 2002. Groundwater Quality: Mozambique Ferro, B.P.A. and D. Bouman, 1992. Hydrogeological Map of Mozambique, scale 1:1,000,000 Christelis, Greg and Wilhelm Struckmeier. Groundwater in Namibia, an explanation to the Hydrogeological Map. December 2001 Margane, A., Baeumle, R., Schildknecht, F. and A. Bittmer, 2005. Groundwater Investigations in the Oshivelo Region – Main Hydrogeological Report, Unpubl. technical report prepared for Technical Cooperation Project "Investigation of Groundwater Resources and Airborne-Geophysical Investigation of Selected Mineral Targets in Namibia", Volume IV.GW.1.1, BGR archive no. 0125832 : 4,1, 198 p.

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Global Groundwater Region 17: East African basement and Madagascar	
Countries included	Sudan, Democratic Republic of Congo, Uganda, Kenya, Tanzania, Zambia, Mozambique, Zimbabwe, Madagascar.
Generalized hydrogeological setting	This region includes moderate elevated, flat areas of the East African Shield, affected in the Eastern parts by rifting. The region is dominated by outcropping crystalline Basement rocks, with local occurrence of volcanic rocks and sediments. Climate is humid in the Northern parts and dry in the South. Groundwater resources are limited. a) East Congo Precambrian Belt b) Luffilian Arch (Katanga system) c) East Kalahari Precambrian Belt d) East Africa Basement (including rifted zones) e) Tanzania coastal basin f) Sediments of Madagascar g) Basement of Madagascar Groundwater in crystalline rocks is restricted to local pockets of weathered or fractured zones or to shallow layers of fluvial sediments. Coastal sediments (e.g. Karoo Sandstone in Tanzania) have favourable groundwater conditions. High fluoride concentrations occur locally.
Adequacy of information accessed on saline groundwater	
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* Due to great differences in climate, relief and geology a general picture is difficult to give. Because basement is the main geological factor water is spatially wide spread in smaller and local aquifers. The coastal sediments can harbour larger aquifers and seawater intrusion is mentioned near larger settlements. In some older formations, within the southern coastal basins in Madagascar, relict saline water is found (A1) (122). The coastal plains of Tanzania are vulnerable to marine intrusion where groundwater pumping rates are high, e.g. at Dar es Salaam 1700 mg/l (A4) (123). The northern coast in Mozambique has mainly brackish to salty groundwater with TDS > 1500 mg/l (A1, A4) (109). In Madagascar some coastal aquifers suffer from saline intrusion and by infiltration of salt water from near-coastal rivers (A4). In Tanzania the groundwater in the Northern central area (124) has a quality that ranges from poor to fair (B0). Salinities can go up to 3 g/l. Around lake

	Rukha, an endorheic lake, groundwater is observed to be saline (B1) (125). In Zimbabwe salinity is a problem in the plain deposits of the Mzingwane catchment in the semi-arid areas B1) (126). The Limpopo catchment in Botswana has TDS values of 1000-1500 mg/l for most of the area, while increased levels of nitrates are occurring near irrigation and within settlement areas (D0) (127). In the alluvial aquifers of the lower Shire (B2) (128) in Malawi, sporadic saline water occurs due to dissolution of evaporative minerals (up to 4 g/l). In the South Rukuru catchment (129) (B5) in the Northwest of Malawi, high salinity has also been noted. Fluoride is found in the Malawi Rift zone (Eastern alluvial plains) (B1, B2). In the Northern uplands of Mozambique fluoride is a problem in the Rift along the border with Malawi (B2). In some Eastern parts of Uganda (130), high salinity values are encountered in the volcanic zones (chloride of several thousand mg/l). Fluoride is found in the Rift Valley, e.g. around the crater lakes and Ruwenzori Mountains in the West and the Sukulu Hills in the East (B0) (131).
Current or potential threats of saline groundwater to the interests of society or ecosystems	
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	
Human responses to threats and or opportunities(management)	
Impact of expected or observed global change	
Selected references	British Geological Survey and WaterAid, 2001. Groundwater Quality: Uganda British Geological Survey and WaterAid, 2002. Groundwater Quality: Madagascar British Geological Survey and WaterAid, 2002. Groundwater Quality: Mozambique British Geological Survey and WaterAid, 2002. Groundwater Quality: Tanzania British Geological Survey and WaterAid, 2004. Groundwater Quality: Malawi FAO, 2004. Drought impact mitigation and prevention in the Limpopo river basin, a situation analysis, Land and Water Discussion Paper, No. 4 Ferro, B.P.A. and D. Bouman, 1992. Hydrogeological Map of Mozambique, scale 1:1,000,000 Moyce, W.M., Mangeyaa, P., Owena, R., and D. Love, 2006. Alluvial aquifers in the Mzingwane catchment: Their distribution, properties, current usage and potential expansion, *Physics and Chemistry of the earth*, Vol. 31, pp. 988-994 UNESCO-IHP, 2002. Managing Shared Aquifer Resources in Africa; Proceedings of the International Workshop Tripoli, Libya, 2-4 June 2002, IHP-VI, Series on Groundwater No. 8

Global Groundwater Region 18: Volcanics of East Africa	
Countries included	Ethiopia, Kenya.

Generalized hydrogeological setting	This region includes the moderate to high-elevated part of the East African Craton that has been affected by rifting and volcanism. In the rifted zone, large fault escarpments and steep slopes of volcano's dominate the relief. Arid to semiarid climate prevails, with humid zones in higher elevated areas. Groundwater resources are variable. a) Amhara Plateau b) Eastern Branch of East African Rift Valley Groundwater in crystalline rocks is restricted to local pockets of fractured and weathered zones or shallow layers of alluvial sediments. In volcanic areas groundwater occurs in fractured zones and in the sediments inter-bedded between successive lava flows ("old land surfaces"). Groundwater may contain high concentrations of fluoride and is often hot and brackish in the Rift Valley.
Adequacy of information accessed on saline groundwater	
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* Groundwater in this region is often affected by dissolution of minerals in the volcanic rocks (B2). In Djibouti large areas outside the wadis contain brackish or saline groundwater (132). This saline groundwater is manifested in the form of thermal salty springs. Salinity can reach over 4 g/l (B4). Throughout the Awash river basin in Ethiopia, salinity problems are recognized (B2) (133). In Kenya saline groundwater is encountered near the saline lakes in the Rift Valley (134) and the rivers Embakasi and Athi (135). The origin of the mineralization is the dissolution of volcanic ashes and the high evaporation afterwards (B5). *Highly saline brines:* The Danakil depression in Ethiopia and Eritrea contains groundwater with very high levels of solutes. The area is geothermal active and due to excessive evaporation thick salt crusts are encountered. In general the Southern part is more mineralized than the Northern part (B0) (136).
Current or potential threats of saline groundwater to the interests of society or ecosystems	
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	
Human responses to threats and or opportunities(management)	
Impact of expected or observed global change	
Selected references	British Geological Survey and WaterAid, 2001. Groundwater Quality: Ethiopia FAO, 2008, Gateway to Land and Water Information: Djibouti,

	http://www.fao.org/ag/Agl/swlwpnr/reports/y_nr/z_dj/dj.htm, consulted at October 2008 FAO, Land Degradation Assessment in Dry Areas (LADA), 2008. http://www.fao.org/nr/lada/, consulted at October 2008 Mwango, F.K., Muhangù, Juma, C.O. and I.T. Githae, 2002, Groundwater resources in Kenya, in Appelgren, B. (ed.), Managing Shared Aquifer Resources in Africa, Proceedings of the International Workshop Tripoli, Libya, 2– 4 June 2002 Taddese, G., Sonder, K. and D. Peden, 2004, The water of the Awash river basin a future challenge to Ethiopia, IWMI Working paper

Global Groundwater Region 19: Horn of Africa basins	
Countries included	Ethiopia, Somalia, Kenya.
Generalized hydrogeological setting	This region includes large depressions in basement rocks that have been filled by sediments of various origins. Locally isolated uplifted Basement complexes occur. Southern en central parts are flat and moderate-elevated. Northern parts have more pronounced relief. Arid to semiarid climate prevails, with humid zones in higher elevated areas. Groundwater resources are variable. a) Ogaden Basin b) Somali Coastal Basin Groundwater in crystalline rocks is restricted to local pockets of fractured and weathered zones or shallow layers of alluvial sediments. The sedimentary rocks have variable groundwater potential. Sandstones and fractured limestones are permeable and have good yields, although water levels are in place deep. Interbedded silt and clay horizons form barriers to groundwater flow. The best aquifers are found in coarse Quaternary alluvial sediments in the floodplains of major rivers. Dissolution of evaporates occurring in central horizons of sediments causes increased salinity of groundwater.
Adequacy of information accessed on saline groundwater	
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* Most of the area lies in arid to semi-arid climate zones. Groundwater here lacks completely or is highly mineralized. At the coastal zones intruded seawater can be encountered besides pockets of fresh water. In the coastal area of Kenya and Somalia relict marine seawater can be encountered in former reefs (A1) (137). In larger settlements at the coast of the region, seawater intrusion due to over-extraction is becoming a problem (A4). Part of the salinity of deeper groundwater in the paleo-channel of Northeast Kenya (Merti aquifer) is either relict seawater or of evaporative origin (A1, B1) (138). In the Southern part of the Ogaden desert (139) no fresh shallow groundwater is found. This is also the case in many places in (South)eastern Kenya and along the Southern shores of the Shebele river in Somalia (139). In these areas the salinity source is mainly the dissolution of evaporative minerals and high evaporation rate (B5). In many parts of Somalia brackish and saline groundwater is encountered besides pockets of fresh water. The distribution is very irregular. In Kenya saline groundwater is encountered in

	dryer parts of Kitui, Garissa and Isiolo districts (B5) (140).
Current or potential threats of saline groundwater to the interests of society or ecosystems	
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	
Human responses to threats and or opportunities(management)	
Impact of expected or observed global change	
Selected references	Faillace C. and E.R. Faillace, 1986, Water Quality Data Book of Somalia., GTZ, Rome Organization of African Unity, 1992. International Hydrogeological Map of Africa, 1: 5,000,000, Algeria UNESCO-IHP, 2002. Managing Shared Aquifer Resources in Africa; Proceedings of the International Workshop Tripoli, Libya, 2-4 june 2002, IHP-VI, Series on Groundwater No. 8 WHYMAP, 2007/2008. Groundwater Resources of the World, 1: 25,000,000

Asia

Global Groundwater Region 20: West Siberian platform	
Countries included	Russia
Generalized hydrogeological setting	This region includes the low to moderate elevated, flat areas of West Siberian craton that has been rifted and filled by thick sedimentary sequences. Upper part of these sequences consists predominantly of alluvial-lacustrine sediments. Climate is cold and dry. In the Northern parts of the region is a belt of permafrost. Groundwater resources are abundant. Main physiographic units or geological provinces: a) Yenisey Basin b) West Siberian Basin c) Turgay Depression (basin) Unconsolidated sediments show large variations in grain size. Main aquifers are associated with layers of coarse material in alluvial sediments. Fractured sandstones form local aquifers.
Adequacy of information accessed on saline groundwater	A limited number of English papers on groundwater salinity are found and consulted. Most papers are on saline lakes, salt, oil and gas exploration and hydrothermal systems and have only proxy information on groundwater salinity. Papers in the Russian language were not consulted.
Main occurrences, origin and dimensions of shallow	*General picture:* The relative absence of information on groundwater suggests that saline groundwater at shallow and an intermediate depth (<

saline groundwater	500 m deep) is not abundantly present or at least is not an issue.
Current or potential threats of saline groundwater to the interests of society or ecosystems	Not mentioned in consulted papers
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Not mentioned in consulted papers
Human responses to threats and or opportunities(management)	Not mentioned in consulted papers
Impact of expected or observed global change	Not mentioned in consulted papers
Selected references	

Global Groundwater Region 21: Central Siberian plateau	
Countries included	Russia
Generalized hydrogeological setting	This region includes the moderate elevated areas of Central Siberian craton, including large basins separated by uplifted highs and arches of crystalline rocks. Numerous rivers have further modified the relief of the region. Climate is cold and dry. In the Northern half of the region is a belt of permafrost. Main physiographic units or geological provinces: a) Tunguska Basin b) Cis-Sayan Basin c) Lena-Vilyuy Basin d) Anabar-Olenek High e) Nepa-Botuoaba Arch f) Aldan uplift Groundwater resources are moderate. Alluvia associated with large rivers (e.g. Lena) and fissured limestone and sandstones form potential aquifers. Crystalline rocks have a low groundwater potential restricted to weathered zones. Groundwater distribution is greatly influenced by permafrost.
Adequacy of information accessed on saline groundwater	A limited number of English papers on groundwater salinity are found and consulted. Most papers are on saline lakes, salt, oil and gas exploration and hydrothermal systems and have only proxy information on groundwater salinity. Papers in the Russian language were not consulted.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* The occurrence of saline groundwater at shallow and intermediate depths (< 500 m deep) is assumed for this groundwater region and associated with the presence of evaporates.

	In the Lena-Vilyuy basin in Southern Siberia Cambrian and Ordovician evaporates are found (rock salt exploration NW of Irkutsk and West of Bratsk) (141) (B2). It is assumed that groundwater in the area North-West from Lake Baikal has high salinity levels due to *dissolution of these evaporates* (B2) (see also Groundwater Region 24).
Current or potential threats of saline groundwater to the interests of society or ecosystems	Not mentioned in consulted papers
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Rock-salt and brine exploration, exploration of medicinal mineral water, exploitation of medicinal health spas using high TDS content water
Human responses to threats and or opportunities(management)	Not mentioned in consulted papers
Impact of expected or observed global change	Not mentioned in consulted papers
Selected references	Petrychenko, O.Y., Peryt, T.M., and E.I. Chechel, 2005. Early Cambrian seawater chemistry from fluid inclusions in halite from Siberian evaporates, *Chemical Geology*, Vol. 219, pp. 149– 161 Golonka, J., Bocharova, N.Y., Ford, D., Edrich, M.E., Bednarczyk, J., and J. Wildharber, 2003. Paleogeographic reconstructions and basins development of the Arctic, *Marine and Petroleum Geology,* Vol. 20, pp. 211–248

Global Groundwater Region 22: East Siberian highlands	
Countries included	Russia
Generalized hydrogeological setting	This region includes the moderate to high-elevated areas of East Siberian craton. The craton now is largely covered by thick sedimentary sequences of marine and continental sediments. The relief of the region is related to anticlinal structures in sedimentary rocks. In the Eastern parts of the region, also crystalline rocks crop out in the folded structures. Climate is cold and dry. Almost entire region belongs to the permafrost zone. Main physiographic units or geological provinces: a) Verkhoiansk Range b) Cherskii Range c) Kolyma Plain d) Yukagir Plateau e) Anadyr Range Groundwater resources are limited. Groundwater occurrence is restricted to fractured or weathered zones in crystalline rocks and consolidated sediments. Locally aquifers in unconsolidated alluvial sediments may occur. Groundwater distribution is greatly influenced by permafrost.

Adequacy of information accessed on saline groundwater	No papers found containing relevant information on subject. Papers in the Russian language were not consulted.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* The absence of information on groundwater suggests that saline groundwater at shallow and an intermediate depth (< 500 m deep) is not abundantly present or at least is not an issue.
Current or potential threats of saline groundwater to the interests of society or ecosystems	-
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	-
Human responses to threats and or opportunities(management)	-
Impact of expected or observed global change	-
Selected references	-

Global Groundwater Region 23: Northwestern Pacific margin	
Countries included	Japan, Taiwan, Philippines and parts of Russia
Generalized hydrogeological setting	This region includes the moderate to high-elevated areas of Northwestern Asia associated with the unstable island arch of West Pacific (Circum-Pacific Belt). These areas have pronounced relief, related to uplift of sedimentary rocks and volcanic activity. The sedimentary formations consist mainly of marine sandstones and mudstones, which are intercalated by limestone and granitic intrusions. The climate varies from cold and dry to hot and moist. Main physiographic units or geological provinces: d) Kamchatka Peninsula e) Kuril Islands f) Japan g) Philippines Groundwater occurs in fractured and fissured sandstones and limestone. Porous volcanic rocks and locally thick unconsolidated sediments form productive aquifers (e.g. Tokyo Group Aquifer System). Thermal zones, associated with volcanic activity, effect the groundwater composition.
Adequacy of information accessed on saline groundwater	

Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* The consulted information on groundwater suggests that saline groundwater (< 500 m deep) is not present in large volumes or over large extends at shallow and intermediate depths. Instead there are numerous occurrences of localized areas (mostly coastal) of groundwater salinization that make it noteworthy to mention. The Philippines, Taiwan and Japan are often hit by typhoons and cyclonic storms (in each country about 2-3 typhoons and 3-4 cyclonic storms reach land annually). During these events low-lying and flat coastal and estuarine areas may be *incidentally flooded* (A3), subject to *seawater intrusion* (A4) and *sea-sprays* (A5) (142). The Philippines, Taiwan and especially Japan are densely populated with relatively a large portion of the population living in the coastal areas and coastal cities. Drinking water supplies in many of the coastal areas are heavily depending on groundwater pumping. Groundwater overexploitation in the last few decades has lead to many occurrences of groundwater salinization due to *seawater ingress*. Examples of such areas are Kanto plain (Tokyo, Kawasaki, Yokohama) (143), Nobi plain (Nagoya) (144) , the Osaka plain (Osaka, Kobe) (145) and Nagasaki (146) in Japan, Taipei city in Taiwan (147) and Cebu city, Iloilo, Dagupan, Cavite, Zamboanga, Luzonc and Manilla in the Philippines (148 to 153). Groundwater overexploitation for agricultural purpose has lead to *lateral seawater intrusion* and consequent groundwater salinization in the coastal stretches of the Shiroishi plain in Japan (154) and in the Pingtun plain (155) and Choshuichi plain in the Western part of Taiwan (156) (A4). This Northwestern Pacific area is part of the so-called ring of fire, an area with intensive tectonic and volcanic activity. Many occurrences of hydrothermal systems are found stretching from Kamchatka, the Kuril Islands, Japan and Taiwan to the Philippines. Groundwater associated with these *hydrothermal systems* often has a TDS content ranging from brackish to hypersaline (B4) (157). Some hydrothermal systems located relatively close to the coast appear to be hydraulically connected to the seawater (like the Taal volcano system on the Luzón island, Philippines) (158). Part of its groundwater salinity can be explained by seawater mixing. Leakage *(pollution)* of brackish and saline water from aquaculture ponds in coastal areas (fish and shrimp production in especially Philippines and Taiwan) lead to localized spots of salinization of the underlying groundwater (C2) (159 and 160). Parts of this region have also been affected by the 2005 tsunami. See also Groundwater Regions 32 and 33 (161).
Current or potential threats of saline groundwater to the interests of society or ecosystems	Not mentioned in consulted papers
Current or potential	Not mentioned in consulted papers

benefits (opportunities) of saline groundwater to the interests of society or ecosystems	
Human responses to threats and or opportunities(management)	Not mentioned in consulted papers
Impact of expected or observed global change	Not mentioned in consulted papers
Selected references	Delmelle, P., Kusakabe, M., Bernard, A., Fischer, T., de Brouwer S., and E. del Mundo, 1998. Geochemical and isotopic evidence for seawater contamination of the hydrothermal system of Taal Volcano, Luzon, the Philippines, *Bulletin of Volcanology*, Vol. 59, pp 562–576 Don, N.C., Araki, H., Yamanishi, H. and K., Koga , 2005. Simulation of groundwater flow and environmental effects resulting from pumping, *Environmental Geology*, Vol. 47, pp 361–374 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=phillipines, consulted at October 2008 Kononov, V. I., 2002. Geothermal Resources of Russia and Their Utilization, *Lithology and Mineral Resources*, Vol. 37(2), pp. 97–106 Scholze, O., Hillmer G. and W. Schnieder, 2002. Protection of the Groundwater Resources of Metropolis Cebu (Philippines) in Consideration of Saltwater Intrusion into the Coastal Aquifer, 17th Salt Water Intrusion Meeting, Delft, The Netherlands, 6-10 May 2002 World Bank Group, 2003. Philippines Environment Monitor 2003, Water Quality

Global Groundwater Region 24: Mountain belt of Central and Eastern Asia	
Countries included	Parts of Russia, Kazakhstan, Mongolia and China and the countries North Korea and South Korea
Generalized hydrogeological setting	This region includes the high-elevated areas of Central and East Asia associated with Paleozoic Mobile Belt. As result of intensive folding, the region has a steep relief. Crystalline rocks dominate the surface in the Northern half of the region. In the Southern half, crystalline and volcanic rocks alternate with consolidated and unconsolidated sediments. Main physiographic units or geological provinces: a) The Altay-Sayan Folded Region (Central Siberia-Mongolia Border) b) Mongol-Okhotsk Folded Region c) Baikal-Paton Folded Region (surroundings of Lake Baikal) d) Aldan Shield in Eastern Siberia e) Yinshah Da and Xia Hinggannling Uplift (Yablonovy and Khingan ranges) f) Sikhote-Alin Folded Region (South-East Siberia) g) Korean Peninsula Groundwater resources are limited to moderate. Local aquifers occur in intermontane alluvial systems, fractured volcanic rocks, and karstified carbonates. Crystalline rocks have a low groundwater potential,

	restricted to the thickness of the weathered zone. Highlands have low precipitation and high evaporation, while coastal areas have a moist climate. Groundwater resources are limited to moderate.
Adequacy of information accessed on saline groundwater	Limited amount of direct and relevant information on groundwater salinity. Indirect and proxy data on saline lakes, saline soils.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture*: In this groundwater region, the saline groundwater occurrences with the largest areal extent are found in the arid Central Asian area where a large number of endorheic basins are found. Intensive groundwater exploitation from relatively shallow aquifers at the Western and Southern coasts of China and North and South Korea for irrigation purposes (C1) has lead to *lateral seawater intrusion* (A4) (162 to 165) In severe cases, the salinity problems arise in zones up to 10 km landward. Likely other marine origins of groundwater salinity are present in these areas. In most other parts of the coastline of this groundwater region there is low hydraulic connectivity between the land and the sea and hence the potential occurrence of groundwater salinity from coastal origin is small. In this zone a large number of endorheic basins are found. Some of these closed basin form lakes while other are basins with relatively shallow groundwater tables. Groundwater salinity in many of these closed basins (and also the surface water) is high due to *continuous evaporation of the shallow groundwater and lake water* (B1) Examples of saline lakes and playas in this region are: - many small saline lakes in the Kundula steppe in Southwestern Siberia and Northern Kazakhstan (166); - intermontane lakes in Mongolia (Uvs Nuur, Har Us Nuur, Döröö Nuur, Kövgül Nuur, Hyargas Nuur (167 to 171); - Khakasia lakes (172); - Galbïn Govĭ in Southeastern Mongolia (173) In the Khakasia area, Devonian evaporates (B2) (174) are present resulting in increased salinity of the groundwater and lake water in this area. In this region, part of a large zone of *hydrothermal active systems* is found stretching from the Arctic Sea in the North to the Mongolian border in the South. This Lena-Vilyuy basin in NW-Siberia contains many occurrences of Cambrian and Ordovician evaporates of hydrothermal origin (141). Most of the hydrothermal systems are located at considerable depth (more than 500 meter below surface level). However, occasional shallower subsystems with groundwater with high TDS content are assumed (B4). Lake Baikal is an open basin with a fresh water surface. Discharge of *hypersaline thermal groundwater* however is observed at various parts of the lake bottom (B4) and assumed to occur doe to dissolution of the mentioned evaporates (B2) (175).
Current or potential threats of saline	Possible threat of drinking water quality deterioration in saline groundwater areas and crop yield decline in coastal aquifers of Korea

groundwater to the interests of society or ecosystems	
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Rock-salt and brine exploration, exploration of medicinal mineral water, exploitation of medicinal health spas using high TDS content water
Human responses to threats and or opportunities(management)	Seawater intrusion monitoring is conducted in the affected coastal aquifers of South Korea.
Impact of expected or observed global change	Not mentioned in consulted papers
Selected references	Banks, D., Parnachev, V.P., Frengstad, B., Holden, W., Karnachuk, O.V., and A.A. Vedernikov , 2004. The evolution of alkaline, saline ground- and surface waters in the Southern Siberian steppes, *Applied Geochemistry,* Vol. 19, pp. 1905–1926 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=china, consulted at October 2008 Lee, J.Y., and Song, S.H., 2007. Evaluation of groundwater quality in coastal areas: implications for sustainable agriculture, *Environmental Geology*, Vol. 52, pp. 1231–1242 Parnachev. V.P., Banks, D., Berezovsky, A.Y. and Garbe-Schönberg, D., 1999, Hydrochemical evolution of Na-SO4-Cl groundwater in a cold, semi-arid region of Southern Siberia, *Hydrogeology Journal,* Vol. 7, pp. 546-560 Park, S.C., Yun, S.T., Chae, G.T, Yoo, I.S., Shin, K.S., Heo, C.H. and Lee, S.K., 2005. Regional hydrochemical study on salinization of coastal aquifers, Western coastal area of South Korea, *Journal of Hydrology*, Vol. 313, pp. 182–194 Zekster, I.S., 1995. Groundwater discharge into lakes: A review of recent studies with particular regard to large saline lakes in central Asia, *International Journal of Salt Lake Research*, Vol.4 (3), pp. 233-249 Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Global Groundwater Region 25: Basins of West and Central Asia	
Countries included	Turkmenistan, Uzbekistan, Kazakhstan, Kyrgyzstan, Tajikistan, parts of the countries China, Afghanistan, Iran (North), and Mongolia (South)
Generalized hydrogeological setting	This region includes the low to moderate elevated, relatively flat areas of West and Central Asia. Low elevated Western part of the region is associated with huge geo-syncline containing a thick sequence of sedimentary rocks. In Western parts, the sedimentary basins are separated by more elevated areas containing crystalline rocks. Unconsolidated alluvial and aeolian deposits cover large areas. Climate is arid to semi-arid. Main physiographic units or geological provinces: a) Central Kazakhstan Folded Region b) Syr-Darya basin c) Tian Shan Foldbelt

	d) Junggar Basin e) Tarim Basin f) Altushan Fold Belt g) Jinguan Minle Wuwei Basin h) Erdos Basin i) Shauxi Plateau j) Taihangshan Yanshan Fold Belt Groundwater resources are variable. Regional aquifers occur in fractured sandstones, karstified limestone (e.g. Erdos Basin aquifer) and alluvial sediments. Groundwater in extensive loess deposits is associated with the presence of permeable paleo-soils. These horizons are an important water source. Modern recharge is very limited.
Adequacy of information accessed on saline groundwater	Limited amount of relevant literature can be found on groundwater salinity related to closed basins and saline lakes and to irrigation.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture*: In this global groundwater region, the areal presence of saline groundwater is rather extensive. The salinization of the groundwater has far reaching consequences in the Amu Darya, Syr Darya river basins and the Aral Sea. The recent rise in the Caspian Sea level resulted in *flooding of the low-lying flat area of Kazakhstan with saline lake water* (A3) In this groundwater region, a number of large closed basins can be found (Amu Darya, Syr Darya in Turkmenistan, Uzbekistan and Kazakhstan, Junggar, Tarim and Heixi basins in China. These basins often act as groundwater discharge zones and receive also surface water from various inland rivers. In many of these closed basins, saline lakes can be found (Lake Sarakamysh in Turkmenistan (176), Aral Sea (177) and Balqash (178), Tengiz (179), Ozero (180) and Zaysan lakes in Kazakhstan (181), Ysyk Kul in Kirgizstan (182). High levels of groundwater salinity are observed near to these saline lakes (up to more than 10 g/l). The origins of the salinity in these basins are partially caused by the uptake of *weathered rock solubles* (B2) by the regionally travelling groundwater. Moreover the closed basins act as *regional evaporative sinks enriching the remaining surface water in the lakes and the remaining groundwater with dissolved salts* (B1). In a zone roughly located around lake Balqash, the Shu and Illi rivers basins (183), the Tian Shan area (184) and the Northern part of the Tarim basin (185 to 191) near the city of Aksu, various Cambrian, Permian and Carboniferous evaporates are found. The salinity of the groundwater in these areas can be explained by *dissolution of these salt formations* (B2 and B5). In the former Soviet Union era large-scale food production (especially cereals) was established and is still in use in the Central Asian area. (192 to 196) . This area has a high aridity index and hence most of the agriculture production takes place under irrigated conditions. This large-scale and intensive irrigation caused various environmental degradation effects in the area of which the Aral Seawater level decline

	and the associated ecological and socio-economic is well known. In many of the *irrigation* areas groundwater salinity is high (C1/C2) due to *water logging effects, application of irrigation water with high initial TDS content and intensive use of artificial manure and pest-control inputs*.
Current or potential threats of saline groundwater to the interests of society or ecosystems	The rising soil and groundwater salinity levels in many of the irrigated areas and the possible declining agricultural yield are of great concern and are mentioned in various governmental documents.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Not mentioned in consulted papers
Human responses to threats and or opportunities(management)	Various salinity control measures in the irrigation areas are mentioned in governmental policy documents
Impact of expected or observed global change	Not mentioned in consulted papers.
Selected references	Aladin N.V. and Plotnikov, I.S., 1993. Large saline lakes of former USSR: a summary review, *Hydrobiologia,* Vol. 267, pp. 1-12 Ibrakhimov, M., Khamzina, A., Forkutsa, I., Paluasheva, G., Lamers, J.P.A., Tischbein, B., Vlek, P.L.G. and Martius, C., 2007. Groundwater table and salinity: Spatial and temporal distribution and influence on soil salinization in Khorezm region (Uzbekistan, Aral Sea Basin), *Irrigation and Drainage Systems*, Vol. 21(3-4), pp. 219-236 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=china, consulted at October 2008 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=iran, consulted at October 2008 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=uzbekistan, consulted at October 2008 Ji, X., Kang, E., Chen, R., Zhao, W., Zhang, Z. and Jin, B., 2006. The impact of the development of water resources on environment in arid inland river basins of Hexi region, Northwestern China, *Environmental Geology*, Vol. 50, pp. 793–801 O'Hara, S.L. and Hannan, T., 1999. Irrigation and Water Management in Turkmenistan: Past Systems, Present Problems and Future Scenarios, *Europe-Asia Studies*, Vol. 51(1), pp. 21-41 Zekster, I.S., 1995. Groundwater discharge into lakes: A review of recent studies with particular regard to large saline lakes in central Asia, *International Journal of Salt Lake Research*, Vol.4(3), pp. 233-249 Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Global Groundwater Region 26: Mountain belt of West Asia	
Countries included	Turkey, Iran, parts of Georgia, Armenia, Azerbaijan, parts of Iraq,

	Turkmenistan, Afghanistan and Pakistan
Generalized hydrogeological setting	This region includes high-elevated areas of West Asia, belonging to the Alpine-Himalayan Mobile Belt (Taurus Mountains, Anatolian Plateau, Caucasus, Central Iranian Basins, Elburz Mountains and Zagros Fold belt and Trust zone). Also included are medium elevated sedimentary basins associated with tectonic structures. The folded areas have complex lithology with altering crystalline, volcanic and sedimentary rocks. Sedimentary depressions containing predominately marine sediments (carboniferous rocks and sandstones). Basins are locally covered with thick layers of unconsolidated sediments. Climate is predominantly dry, with some moist zones in the higher altitudes. Main physiographic units or geological provinces: a) Taurus Mountains b) Anatolian Plateau c) Caucasus d) Central Iranian Basins e) Elburz Mountains f) Zagros Fold belt and Trust zone (Zagros Mountains) Groundwater resources are low to moderate. Alluvial and colluvial fill of relative flat areas form local aquifers in the mountains. In the sedimentary basins, karstified limestone (e.g. Midyat Aquifer in Turkey) are major groundwater sources. Fractured sandstones and unconsolidated sediments can also form interconnected aquifer systems. The groundwater yield of unconsolidated sediments is high in the alluvial deposits directly connected to the riverbeds.
Adequacy of information accessed on saline groundwater	
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* This global groundwater region has various occurrences of saline groundwater. The combined geological, climate, hydrological and socio-economic setting results in the fact that about all genetic categories of groundwater salinization are present in this region. In the Makran coastal areas of Baluchistan (198), Pakistan various sedimentary aquifers are present with *connate groundwater of marine origin* (A1). The Caspian Sea with a salinity of about 1/3 of seawater salinity experienced fluctuating water levels of meters. During the last decades, water level rose 3 meters resulting in flooding and lateral intrusion of the saline lake water in its coastal regions (A2) (199). Areas with *lateral seawater intrusion* can be found in the South-Western coast of Iran and near various coastal cities in Turkey (A4) (200 and 201 to 203). In this groundwater region, many closed basins are found in a semi-arid climate. *Continuous evaporation* leads to salinization of the lakes and playas. Nearby groundwater resources often measure high levels of salinity (e.g. Tuz Gölü (204), Van Gölü (205) and Egridir Gölü (206) in Turkey, Urmia lake, the intra-montane basins in the Zagros mountains (207 to 212), the playas of Dasht-e-Kavir in Iran (213), Western Baluchistan in Pakistan, (B1).

	Iran is rich in evaporate deposits, which were deposited episodically throughout the Phanerozoic and can be found at shallow depths in the Gulf area, Zagros mountains and the Great Kavir basin (214 to 222) in Central Iran. Also Turkey has various salt-bearing formations (223). Groundwater in these areas has high salinity due to *dissolution of these subsurface salts* (B2). The area is tectonically active (earthquakes, volcanism) resulting in numerous occurrences of *highly saline thermo-mineral groundwater* (B4) in Northern and Southern Caucasus mountains (224 and 226). Large-scale and *intensive irrigation* in parts of Turkey (227 to 229) and especially Azerbaijan (Kura Aras Lowlands) (230) has lead to high levels of *secondary salinization* (C1).
Current or potential threats of saline groundwater to the interests of society or ecosystems	The externalities of secondary salinization in Turkey, Iran and Azerbaijan are discussed in many articles and policy reports.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Thermo-mineral waters are sometimes used for health purposes (spas, mineral water).
Human responses to threats and or opportunities(management)	Improving irrigation techniques
Impact of expected or observed global change	
Selected references	Alekperov, A.B., Agamirzayev, R.C., and Alekperov, R.A, ,2006, Geoenvironmental Problems In Azerbaijan, in Urban Groundwater Management and Sustainability, eds. Tellam, J.H., Rivett, M.O., Israfilov, R.G. and Herringshaw, L.G., NATO Science Series ,Vol. 174 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=iran, consulted at October 2008 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=pakistan, consulted at October 2008 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=turkey, consulted at October 2008 FAO, Aquastat, 2008, http://www.fao.org/nr/water/aquastat/main/index.stm, consulted in June Yechieli, Y. and Wood, W.W., 2002, Hydrogeologic processes in saline systems: playas, sabkhas, and saline lakes, *Earth-Science Reviews*, Vol. 58, pp 343–365

Global Groundwater Region 27: Himalayas and associated highlands	
Countries included	Parts of the countries Afghanistan, Pakistan, Tajikistan, India, Nepal, China, Burma, Thailand

Generalized hydrogeological setting	This region includes high-elevated areas of Central Asia, belonging to the Himalayan Mobile Belt. It is continuation of the West Asian part of this belt (Region 24). The folded areas have complex lithology with altering crystalline, volcanic and sedimentary rocks. Climate varies from warm and humid to cold and arid. Large areas are covered by glaciers or seasonal snow. Main physiographic units or geological provinces: a) Hindu Kush b) Pamir High c) Tibetan Plateau d) Himalayas e) Shan Plateau f) Tenasserim Mountains Groundwater resources are limited. Alluvial and colluvial fills in relative flat areas might form extensive aquifers (e.g. Kathmandu Valley) in the mountains. Local aquifers also occur in karstic limestone and fractured sandstones.
Adequacy of information accessed on saline groundwater	Most of this high-altitude and often semi-arid region is remotely located with low economic potential and hence has a low population density. Consequently groundwater studies in this area are sparse.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture*: Occurrences of saline groundwater in this region is rather limited and associated with the terrestrial origins (evaporation from closed basins and dissolution of underground salt formations). Consequences of the groundwater salinization are small because of the low population density. The Tibetan and Shan plateaus in China (231) are dotted with many lakes which have a tectonic (intramontane basins, strike-slip basins) and/or glacio-fluvial origin (Pleistocene glaciations). 40% of these lakes (in total 21,400 km^2) are closed basins and produce brackish and saline waters and playas due to *evaporation*. The Qarhan playa in the Qaidam basin on the Northern part of the Shan plateau has an areal extent of 6000 km^2 and is considered the largest playa in the world. The shallow groundwater adjacent to these lakes is often of brackish or saline quality (B1). Carboniferous salt domes and salt bearing rock strata are found on the plateau (Lhasa region, Qaidam basin) and in the Sichuan basin (232 and 233). Groundwater in these regions is salinized due *to dissolution of these salt formations* (B2). In the Sichuan basin, brine springs are observed.
Current or potential threats of saline groundwater to the interests of society or ecosystems	Not mentioned in consulted papers
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Salt exploitation on the Chinese plateaus and brine exploitation in the Sichuan area have been a major economic activity throughout history in these areas.

Human responses to threats and or opportunities(management)	Not mentioned in consulted papers
Impact of expected or observed global change	Not mentioned in consulted papers
Selected references	FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=china, consulted at October 2008 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=pakistan, consulted at October 2008 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=thailand, consulted at October 2008 Mianping, Z., 1997. *An Introduction to Saline Lakes on the Qinghai-Tiber plateau*, Kluwer Academic Publishers Yang, L., and Liu, Z., 1992. A study of hot brine and its comprehensive utilization for salt chemical industry in Sichuan Basin, P.R. China, *International Journal of Geothermal Research and its Applications*, Vol. 21:5(6), pp 801-809 Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Global Groundwater Region 28: Plains of Eastern China	
Countries included	Eastern China
Generalized hydrogeological setting	This region includes the low to medium elevated areas of Great Plains of Eastern China. Thick sequences of alluvial and aeolian sediments were deposited in sedimentary basins. Region receives low to medium precipitation. Main physiographic units or geological provinces: a) Manchurian Plain b) North China Plain c) Middle and Lower Chang Jiang (Yangtze) River Basin Groundwater resources are abundant. Extensive alluvial aquifers (e.g. Huang-Huai-Hai Plain) store large volumes of groundwater. This region obtained its separate status also due to a very high population density. The bulk of the population of East Asia lives in this region.
Adequacy of information accessed on saline groundwater	
Main occurrences, origin and dimensions of shallow saline groundwater	*Global picture:* This global groundwater region has highest overall population density from all regions. Groundwater demand and use is consequently high. Most of the spatially extensive groundwater salinization found in this region can be explained by groundwater over-use and water mismanagement. The Yangtze and Yellow river deltas most likely contain *marine sediments with connate water* (A1) (234 and 235).

	The Yellow sea coast of Eastern China has been subject two at least two *major Late Pleistocene transgressions* This resulted in an alternating sequences of freshwater and saline water in the Jiangsu area North of Shanghai and in the Huang-Huai-Hai Plain . Even Beijing was sea flooded during the transgression (A2) (236). The low lying coastal areas of China at the Yellow Sea have been subject to numerous storm surges which has introduced additional *seawater flooding of coastal aquifers* (A3) (237). Groundwater exploitation in this area is enormous. This is not surprising when you consider the very high population number and predominantly agricultural (irrigated) land use in this area. *Seawater intrusion* (A4) has been observed in many large coastal cities like Shanghai (238), Qingdao, Laizhou and Tianjin (239). Many occurrences of seawater ingress are found in the coastal aquifers of the Shandong and Liaodong peninsulas. River runoff of many large Chinese rivers is increasingly committed to upstream allocations (dams and reservoirs and irrigation works). A resulting decrease of the freshwater outflow has lead to a salinity ingress in the surface water (directly) and adjacent groundwater (indirectly) in the river estuaries of the Yellow and Yangtze river. The high groundwater demand for the large-scale and intensive irrigated agriculture in the Huang-Huai-Hai Plain (240) has lead to a groundwater table decline of more than 70 meters. This has caused a *lateral inflow of coastal brackish water and of seawater*. In the Heilongjiang region, an annual 2.5% increase in saline groundwater affected surface was found the last decade. Near the cities of Changzhou, Dezhou and even the inland located Handan groundwater has increasingly been salinized because of this process. The *large-scale irrigation* has lead to salinization of shallow groundwater over large areas in the Huang-Huai-Hai Plain and Manchurian river plains due to *water logging. (C1) and application of pumped brackish groundwater*.
Current or potential threats of saline groundwater to the interests of society or ecosystems	The adverse effects of salinization of groundwater resources and soils and threats to domestic water supply and agricultural yields are acknowledged and mentioned by many Chinese scientists and policy makers in papers and reports
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Not mentioned in consulted papers
Human responses to threats and or opportunities(management)	Monitoring of coastal aquifers, improved irrigation (water demand saving, drainage in waterlogged areas), adaptation by growing more salt-tolerant crops
Impact of expected or observed global change	Not mentioned in consulted papers

Selected references	Chen, Z., Chen, Z., and W., Zhang, 1997.Quaternary Stratigraphy and Trace-Element Indices of the Yangtze Delta, Eastern China, with Special Reference to Marine Transgressions, *Quaternary Research*, Vol. 47(2), pp.181-191 Dongguang, W., Xuanmin, W., Eryong, Z., Liangjun L., and W. Dengding, 2007. Issues and Countermeasures on groundwater exploitation and Utilization in China, China Geological Survey FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=china, consulted at October 2008 Fengshu, L., and Xinian, W., 1989, A review of storm-surge research in China, *Natural Hazards*, Vol. 2(1), pp. 17-29 Foster S., and H. Garduño, 2004. China: Towards Sustainable Groundwater Resource Use for Irrigated Agriculture on the North China Plain, Sustainable Groundwater Management, Lessons from Practice, Case Profile Collection, number 8, GW·Mate Hongchun, Z.,1988, Origin, Distribution, and Evolution of Salt-Fresh, Groundwater in North Jiangsu Basin, China, *Environmental Geology Water Science*, Vol. 12(1), pp. 15-22 Wei, W., 2002, Beijing inundated by the sea within the past 80 k.y.: Nannofossil evidence, *Geology*, Vol.30, pp.379-381 Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6 Zhang, Z., Otsubo, K., Zhu, Y. and T. Ishii, 2000. Groundwater Resources and Related Environmental Deterioration in the Hebei Plain, China, LU/GEC Project Report VI, CGER-REPORT CGER-I042-2000, pp. 215–226 Zhang, Z., Otsubo, K. and T. Ishii, 2001. Influence of Intensive Land Use on Groundwater Resources in the Hebei Plain, China, *Environmental Science*, Vol.14 (3), pp 297-304

Global Groundwater Region 29: Indo-Gangetic-Brahmaputra plain	
Countries included	Parts of the countries India, Pakistan, Nepal (terrai) and Bangladesh and Myanmar
Generalized hydrogeological setting	This region includes the low elevated and flat reaches of large Asian rivers draining the Himalayas. Thick layers of sediments accumulated in the foredeep, which underlie the Ganges Plain and neighbouring plains. Climate varies from arid to humid as the mean annual rainfall increases from west to east. Main physiographic units or geological provinces: a) Indus Basin b) Ganges Basin c) Brahmaputra Basin d) Irrawaddy Basin Groundwater resources are abundant. Extensive alluvial aquifer system, associated with major rivers draining the Himalayas, is one of the largest groundwater reservoirs in the world.
Adequacy of information accessed on saline groundwater	Various sources of information are available. Most sources deal with the salinization problems in irrigated areas of Pakistan.

Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* This global groundwater region has various occurrences of saline groundwater. The combined geological, climate, hydrological and socio-economic setting results in the fact that about all genetic categories of groundwater salinization are present in this region. Despite the vastness of the groundwater reservoirs, groundwater salinization is partly caused by over-development. In the coastal areas of Sind and Gujarat various sedimentary aquifers are present with *relict saline groundwater from marine origin* (A1) In the Ganges-delta in West-Bengal and Bangladesh and the Irawaddy delta in Myanmar brackish and saline groundwater is present in various areas and at various depths. Parts of the deltaic sediments are of marine facies and contain *connate saline water* (A1). The Ganges delta has been subject to various *marine transgressions* (A2). Low-lying parts of the delta are subject to common *tidal flushing and flooding, incidental extreme flooding* during cyclonic storms and the 2004 tsunami (A7) (241). The Indian Farakka barrage has lead to decreased freshwater flow in some parts of the Bengal delta resulting in seawater ingress in the tidal inlets and consequent *lateral seawater intrusion in the adjacent groundwater systems* (A4) (242). Intensive groundwater development for irrigation purposes has enhanced this process of lateral seawater intrusion in this area, but also in Gujarat (243). In the Indus delta in Pakistan, the Kotri barrage (244)has decreased the freshwater outflow resulting in seawater ingress in both the surface water and groundwater systems (A4). In Saurashtra, Gujarat, intensive groundwater development in the last few decades has caused salinity ingress in the coastal areas (A4). In the Thar desert various playas can be found, relicts from Holocene / Pleistocene lakes (A1, B1?) (245), while in the Cholistan desert area in Pakistan, playas can be found that originated from *currently evaporated* ancient lakes in these areas (B1). In the Western part of Gujarat, the salty marshes of the Rann of Kutch are found (246). This ancient shallow arm of the Arabian Sea changed into a salty inland lake and subsequently into a salty plain or sabkha (B1) when climate became drier and the water evaporated. In some areas of the Indus and Ganges basis the deeper sediments contain salt-bearing strata of probably Cambrian origin (247 and 248). Groundwater from these deeper aquifers in Sind, Punjab in Pakistan and Haryan, Punjab and Uttar Pradesh in India is often to be found brackish and/or saline due to *dissolution of these salt-bearing strata* (B2). *Intensive irrigation* in these areas has lead to severe salinization of soils and shallow groundwater (especially in Pakistan) as a result of water logging and application of water with high TDS content (C1) (249). Seepage (*pollution*) of brackish water from shrimp culture in mainly Bangladesh has lead to salinization of adjacent land and shallow groundwater (C2).

Current or potential threats of saline groundwater to the interests of society or ecosystems	These countries in the regions are all strongly dependent on their agricultural sectors. Irrigation of the lands takes places partly or mostly by means of groundwater. Increased salinization of the soils and shallow groundwater has decreased agricultural yields and hence the food security and economic developments in these areas.
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	Shrimp culture is practiced in areas with brackish groundwater
Human responses to threats and or opportunities(management)	In Pakistan, vast amount of research are conducted and projects implemented to reduce the man-induced salinization in the irrigation commands (improved drainage, advanced irrigation techniques)
Impact of expected or observed global change	The high population density in especially the Ganges plain in India and Bangladesh and the high groundwater dependency in large parts of these agricultural societies make them prone to overexploitation and degradation of natural systems. Bangladesh is considered one of the more vulnerable countries to climate change. Sea level rise may flood large parts of the low-lying land.
Selected references	BGS/WaterAid, 2001. Groundwater quality in Nepal BGS/WaterAid, 2004. Groundwater quality in Bangladesh, BGS/WaterAid, 2004. Groundwater quality in North India BGS/WaterAid, 2004. Groundwater quality in Pakistan Bhattacharya, A.K., Basak, S., Maity, P., Paira, L.K., Sarkar, S. and Maji, S.C., 2004. Hydrogeology of the Bay of Bengal Coast of India with Special Emphasis on Saline Water Intrusion, EJGE paper Coast, 2007. Increasing Salinity Threatens Productivity of Bangladesh, Coast Position Paper 3, http://www.coastbd.org FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=bangladesh, consulted at October 2008 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=pakistan, consulted at October 2008 Misra A.K., and Mishra, A., 2007. Study of quaternary aquifers in Ganga Plain, India: Focus on groundwater salinity, fluoride and fluorosis, *Journal of Hazardous Materials*, Vol. 144, pp 438–448 Qureshi, A.S., McCornick, P.G., Qadir, M. and Aslam, Z., 2008. Managing salinity and water-logging in the Indus Basin of Pakistan, *Agricultural Water Management*, Vol. 95 pp 1-10 Qureshi, A.S., Shah, T. and Akhtar, M., 2003. The groundwater economy of Pakistan, Working Paper 64, Lahore, Pakistan, IWMI

Global Groundwater Region 30: Nubian and Arabian shields	
Countries included	Saudi Arabia, Egypt, Sudan, Ethiopia, Yemen.
Generalized hydrogeological setting	This region includes the low elevated coastal plains, associated with the Red Sea depression, and moderate high areas belonging to the Nubian and Arabian Shields. High elevated, rift-related, volcanic areas are also included in this region. Climate is arid to semi-arid. Red Sea Hills in

	Africa (including parts of Sahara and Ethiopian Highlands). Main physiographic units or geological provinces: a) Red-Sea coastal plains (e.g. Tihama Plains) b) North Western Escarpment Mountains (Midian & Hiraz) c) Asir Mountains d) Arabian Shield (e.g. Najd Plateau) e) Yemen Highlands Groundwater resources are variable. Crystalline rock areas have limited groundwater potential, restricted to local weathered zones. Larger aquifer systems are associated with unconsolidated sediments underlining plains (e.g. Tihama aquifer) and river deltas (e.g. Abyan). Fractured sandstones, limestone and volcanic rocks, underlying the Yemeni Highlands, can form important aquifers.
Adequacy of information accessed on saline groundwater	
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* In the unconsolidated plains near the coast and river deltas seawater is an imported source of saline water (A1). In the basement areas local pockets of brackish or saline groundwater might occur due to high evaporation and dissolution (B1, B2). In fractured sandstones and limestone, pollution is taking place near the larger towns (C2). In the Tihama area (250) along the red sea coast, seawater intrusion is taking place in many places between the wadi outflows by over-extraction of the fresh groundwater aquifer (A1). In the Jizan area (Saudi Arabia) (251), the groundwater measures an EC of over 5 mS/cm due to up-coning deeper brines. Part of the coastal area of Yemen contains only brackish or saline connate or intruded water (A1, A4) (252 to 256). Salinity problems are present in most aquifers in the coastal area of Eritrea. Seawater intrusion can reach 20 km inland (257). Near Oyun Musa, South of Suez in the Sinai there are several brackish springs (B2, Bitter Lakes) (258) In the Eastern escarpment of Eritrea several saline, geothermal springs are found (B4) (259). Salinity is also common in the Northwestern lowlands of Eritrea (B5) (260). In the Sana'a city area groundwater quality is deteriorating resulting from insecure wastewater disposal (C2) (261) .The groundwater around Asmara has high nitrate concentrations.
Current or potential threats of saline groundwater to the interests of society or ecosystems	
Current or potential benefits (opportunities) of saline groundwater to the interests of society or	

ecosystems	
Human responses to threats and or opportunities(management)	
Impact of expected or observed global change	
Selected references	ESCWA, 1999.Groundwater Quality Control and Conservation in the ESCWA Region. E/ESCWA/NR/1999/1, United Nations, New York ESCWA, 2005. Module 12 Groundwater and IWRM, E/ESCWA/ SDPD/2005/WG.1/13, Workshop on "Training of Trainers on the Application of IWRM Guidelines in the Arab Region" Kuwait, 14-18 May 2005 ESCWA, 2005. The Role of Desalinated Water in Augmentation of the Water Supply in Selected ESCWA Member Countries, E/ESCWA /ENR/2001/19, 28 December 2001 FAO-AQUASTAT, 2008. Eritrea, http://www.fao.org/nr/water/aquastat/countries/eritrea/index.stm, consulted at October 2008 Foster S., 2003. Yemen: Rationalizing Groundwater Resource Utilization in the Sana'a Basin, GW·Mate van der Gun, J.A.M. and A.A. Ahmed, 1995, The Water Resources of Yemen; a summary and digest of available information, Report WRAY-35

Global Groundwater Region 31: Levant and Arabian platform	
Countries included	Parts of Turkey, Syria, Lebanon, Palestine, Israel, part of Egypt, Jordan, Saudi-Arabia, Iraq, part of Iran, Kuwait, Bahrain, Qatar, United Arab Emirates, Oman, part of Yemen
Generalized hydrogeological setting	This region includes the low to moderate elevated, predominantly flat areas of the Levant region and Western parts of the Arabian Peninsula. More elevated areas in Oman are also included. Large rift basins were successively filled with sediments of different origin. Climate is arid. Main physiographic units or geological provinces: a) Sinai b) Euphrates-Tigris Basin c) Al Hasa Plain in Saudi Arabia) d) Central arch with Tuwaig Mountains e) Rub-al-Khali Basin f) Marib and Shabwa basins in Yemen g) Masila-Jeza Basin (with wadi Hadramawt) h) Mountains and plains of Oman Groundwater resources are abundant in terms of stored volumes, but limited in terms of replenishment. Large regional aquifer systems are found in sandstones (e.g. Mukalla Aquifer System) and fissured carbonates (e.g. Umm-Er-Rhaduma Aquifer System). Unconsolidated alluvial sediments along main wadis form local aquifers.
Adequacy of information accessed on saline groundwater	
Main occurrences, origin	*General picture:* Groundwater salinization is a real problem in this

and dimensions of shallow saline groundwater	region. The most important causes for the salinity are the dissolution of the wide-spread evaporates and salt-bearing deposits in this zone and due to intensive irrigation in this arid part of the world. The Khrein sandstone aquifer in the SE of Jordania contains *connate seawater* (A1) (262). The Dead Sea rift valley system has been hydraulically in connection with seawater 3 Ma ago (263). After closing off of the rift valley, evaporation left a brine residue in the system that migrated slowly in a Westward and downward direction. In Israel, still remnants of this hypersaline water can be found (A1, B1) Groundwater salinization due to over-pumping related *lateral seawater intrusion* (A4) has been observed along coastal stretches of Lebanon and Israel (264), Kuwait (265), Yemen (266), Qatar (267), Emirates (268), Iran (269) and Oman (Salâlah and Batinâh coasts) (270 and 271). In this region, various areas with closed basins and local depression are found where surface water accumulates and groundwater discharges (sabkhas). *High evaporation rates* have led to high salinity levels in the groundwater in these zones (B1). Example of such closed basins are Sabkhat al Jabbul near Halab, Sabkhat Mouh near Palmyra (272) and Sabkhat Burghuth North of Abu Kamal in Syria (273), the Azraq oasis region in Jordan (274), the Mesopotamian marshlands near Al Basrah in Iraq (275), the coastal sakbhas in the Emirates (276) and in the far SE corner of Saudi Arabia (277). In the Eastern part of the Arabian peninsula and in the Euphrates-Tigris basin area, many Cambrian and Permian evaporates are situated (278). These evaporates are correlated with those found in Iran. Groundwater flowing from the hinterland towards the discharge zones in the Gulf area becomes enriched in *dissolved salts*. Apart from the evaporates, Palaeogene carbonate sediments are located extensively in this region. Groundwater with *long residence times across the region has dissolved* parts of these sediments and is currently brackish and or even saline in nature (B2) (279). Large-scale and intensive irrigation is found in Turkey (e.g. Çukurova plain and Harran plain) (280 and 281), along the Euphrate between Al Hakkah and Abu Kamal in Syria (282), in Israel and South and East of Baghdad in Iraq (283). *Irrigation induced water-logging, application of brackish groundwater for irrigation input and extensive application of fertilize*r has lead to high levels of total dissolved solids in the shallow groundwater in many of these areas (C1).
Current or potential threats of saline groundwater to the interests of society or ecosystems	
Current or potential benefits (opportunities) of saline groundwater to the interests of society or ecosystems	In some sabkhas found in this region, salt exploration has been a traditional form of livelihood.

Human responses to threats and or opportunities(management)	In Iraq, farmers have adapted to salinization by growing more salt-tolerant crops such as date trees and tomatoes. In the rich Arab oil states and occasionally (some cities and tourist resorts) in the countries along the Mediterranean coast seawater desalinization is used for drinking water production. In Oman, a large number of dams have been constructed in the coastal mountain ranges to decrease runoff and increase groundwater replenishment.
Impact of expected or observed global change	
Selected references	ACSAD, 1984. Water Resources Map of the Arab Countries, sheet 2-B, 1:1.00.000, eds Khouri, J., Droubi, A. and S. Koudmani Bajjali, W, 2005. Model the effect of four artificial recharge dams on the quality of groundwater using geostatistical methods in GIS environment, Oman, *Journal of Spatial Hydrology*, Vol. 5(2) ESCWA, 1999. Groundwater Resources in Palaeogene Carbonate Aquifers in the ESCWA Region: Preliminary Evaluation, United Nations FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=iran, consulted at October 2008 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=syria, consulted at October 2008 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=turkey, consulted at October 2008 IAEA, 1996. Isotope field applications for groundwater studies in the Middle East, Proceedings of the final co-ordination meeting of a regional technical co-operation project held in Ankara, Turkey, 21-25 November 1994 Stanislavsky, E. and H. Gvirtzman, 1999. Basin-scale migration of continental-rift brines: Paleohydrologic modeling of the Dead Sea basin, *Geology*, Vol. 27(9), pp. 791–794

Global Groundwater Region 32: Peninsular India and Sri Lanka	
Countries included	Part of India, Sri Lanka
Generalized hydrogeological setting	This region includes low to moderate elevated areas of the Indian craton. The region is predominantly composed of crystalline rocks. Volcanic (basalt) rocks belonging to the Deccan Trap, cover a large area in the Eastern part of the peninsula. In coastal areas, sedimentary rocks (predominantly sandstones) occur. These rocks might be covered by thick accumulation of unconsolidated sediments especially in the deltas of larger rivers. Climate varies from arid to humid. Main physiographic units or geological provinces: a) Precambrian basement areas in southern and eastern India b) Precambrian basement area of Aravalli Range in Rajasthan c) Precambrian basement and sediments of Sri Lanka d) Deccan Trap e) Coastal sedimentary areas Groundwater resources are low to moderate. Groundwater in crystalline rocks is restricted to local pockets of fractured and weathered zones or shallow layers of alluvial sediments. Sedimentary intercalations

	between lava flows (intertrappeans) are important groundwater sources in volcanic areas. Major deltaic and coastal aquifers, particularly along the East coast, have the highest potential. The coastal zones are prone to seawater intrusion.
Adequacy of information accessed on saline groundwater	The consulted information is derived form various sources like scientific articles, government assessment reports and various websites. Spatial scales in the consulted materials differ from local test cases to state or country scales
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture*: In this global groundwater region, the groundwater salinization is often of marine origin. Because of the high population density and groundwater dependence, consequences of groundwater salinization are relatively high. Along many parts of the coast of India and Sri Lanka, saline and brackish groundwater can be found. In most of these areas, the salinity has multiple marine origins. In geological history, low-lying coastal sedimentary aquifers have been *flooded during marine transgressions* like the Cauvey Delta in Tamil Nadu (A2) (284). Some parts of the current coast strongly interfinger with seawater (tidal creeks in North Maharashtra, lagoonal backwaters in Kerala, various small delta's in Tamil Nadu, Andra Pradesh, Orissa and Sri Lanka and are prone to *regular flooding and spraying* (A7) (285). Orissa's coast has been hit by various cyclonic storms and has suffered *from major flooding in the recent history* (A3) (286). The East coast of India and Sri Lanka were *flooded during the 2005 tsunami* (A3) (161). Often the coastal aquifers are heavily pumped to meet various sorts of water demand that results in *lateral seawater intrusion* (A4) (287). In Kerala extensive sand mining causes additional seawater ingress (288). On top of these mechanisms, *intensive irrigation* in coastal agricultural area has lead to increased salinity of shallow groundwater. Especially in *water logged areas and where irrigation water with high TDS was applied (248 and* 289*).* In Kerala, shrimp aquaculture causes seepage (*pollution*) of saline water from the shrimp ponds into adjacent agricultural lands increasing salinity (C2). The problem of inland salinity has been observed in arid and semi arid regions of Rajasthan, Haryana, with limited extent in the states of Uttar Pradesh, Karnataka, Maharashtra, Madhya Pradesh and Tamil Nadu (290). Salinity is caused by exploitation of deep and old groundwater with *relatively high solutes content (B2)* (291) *and application of irrigation water high TDS* (C1). Furthermore, some large irrigation commands in these areas caused *water logging induced salinization of shallow groundwater C1*.
Current or potential threats of saline groundwater to the interests of society or ecosystems	India with its large population and high population growth and self-sufficiency in food security has recognised the importance of water resources and especially groundwater as a driver for their economic development. Water resources are fully utilised and groundwater quality deterioration is acknowledged. In some areas, groundwater salinity has reached levels beyond potability affecting public health. Other regions application of brackish groundwater has lead to decreased agricultural yields.
Current or potential	In Rajasthan commercial salt production out of highly saline

benefits (opportunities) of saline groundwater to the interests of society or ecosystems	groundwater takes place
Human responses to threats and or opportunities(management)	Various measures are undertaken in many parts of India and Sri Lanka to fight salinity ranging from artificial recharge in coastal areas, agricultural crop adaptation (salt tolerance, less water demanding) and improving water productivity by means of irrigation & drainage efficiency.
Impact of expected or observed global change	Effects of climate change (sea level and aridity index increase), and expected higher water demand as a result of population growth and changed consumption pattern put even more stress on the groundwater resources. The assumed future migration of people to coastal areas puts especially the coastal groundwater resources under jeopardy.
Selected references	BGS/WaterAid, 2004. Groundwater quality in Northern India BGS/WaterAid, 2004. Groundwater quality in Southern India Central Groundwater Board of India, Annual Report. 2002-2003 Deotare, B. C., Kajale, M.D., Rajaguru, S.N., Kusumgar, S., Jull, A. J. T. and Donahue, J.D., 2004. Palaeo-environmental history of Bap-Malar and Kanod playas of Western Rajasthan, Thar desert, *Journal of Earth System Science*, Vol. 113 (3) Ghassemi, F., Jakeman, A.J. and Nix, A.J., 1995. *Salinization of Land and Water Resources: Human Causes, Extent, Management and Case Studies,* Cabi Publishing Government of India, 1981, Development of Coastal Areas Affected by Salinity Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Global Groundwater Region 33: Peninsulas and Islands of South-East Asia	
Countries included	China, Vietnam, Laos, Cambodia, Thailand, Malaysia, Indonesia, Brunei, Papua-New Guinea
Generalized hydrogeological setting	This region includes low to moderate elevated areas of peninsulas and islands of South-East Asia associated with the Circum-Pacific Belt. Tectonic activity in this area produces a complex geological setting. The region is characterised by outcrops of old crystalline rocks, deep sedimentary basins and recent volcanic eruptions. Climate is humid. Main physiographic units or geological provinces: a) South China Fold Belt b) Truong Son Fold Belt c) Thailand Basin d) Khorat Platform e) Tonle Sap-Phnom Penh Basin f) Malay Peninsula g) Sumatra/Java Magmatic Belt h) Sumatra Basin i) Sunda Platform j) Barito-Kutei Basin k) Sulawesi Magmatic Arc

	l) Irian Basins m) New Guinea Mobile Belt Groundwater resources are variable. Groundwater in crystalline and volcanic rocks is restricted to local pockets of fractured and weathered. Unconsolidated sediments (e.g. in Jakarta Groundwater basin) and fissured sedimentary rocks (e.g. karstic zones in Vietnam) form regional aquifers. The groundwater in volcanic areas has a high fluoride concentration.
Adequacy of information accessed on saline groundwater	The availability of relevant documentation on groundwater salinization in this region is limited.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture*: Groundwater salinization in this high precipitation region is mostly limited to localized areas. All genetic categories of groundwater salinity are present in this region. Low-lying Chinese coastal areas between Hong Kong and Shanghai are in the *typhoon susceptible area and have experienced incidental seawater flooding*. Parts of the West coasts of Thailand, Malaysia and especially NW-Sumatra were hit by the 2004 tsunami (161). Extensive parts of the coastal areas (especially Aceh province) were flooded by seawater during this catastrophe causing groundwater salinization (A3). *Lateral Seawater intrusion* into the coastal aquifers are observed in and near the megacities of Hong Kong (292), Ho Chi Minh city (293), Bangkok (294) and Jakarta (A4) (295). This is caused by intensive groundwater pumping for drinking water production and other industrial uses. Coastal groundwater abstraction for irrigation purposes led to seawater intrusion in Guangxi and Xinmowan regions in China (296). *Seawater encroachment in the deltas* of the Pearl river in China (297) and the Red river (298) and Mekong river in Vietnam (299) led to groundwater salinization. The seawater encroachment in these deltas is mainly caused by decreased river discharge because of upstream runoff allocation for irrigation and reservoirs. Deforestation and mismanaged irrigation led to water-logging induced salinization in various areas in this region (B1). Evaporates are found at 50-500 m depths in the Mahasarakham formation in the Korat and Sakon Nakhon basins in NE-Thailand and in the neighbouring provinces in Laos (300). Groundwater in these regions often has brackish to saline characteristics due to dissolution of these salts (B2). In the volcanic active region of Indonesia, various occurrences of *hydrothermal systems* with saline groundwater are found (B4) (301). *Inefficient irrigation* (water logging, leaching of intensely applied agricultural inputs) in especially Red River (302) and Mekong river delta has led to groundwater with high TDS contents (C1/C2). Leakage of brackish and saline water from shrimp farming ponds has result in local *polluted* sites of intense groundwater salinization in many coastal regions in this area.
Current or potential	Decreased agricultural outputs > decreased rural livelihood> rural-

threats of saline groundwater to the interests of society or ecosystems	urban migration
Current or potential opportunities of saline groundwater to the interests of society or ecosystems	
Human responses to threats and or opportunities(management)	
Impact of expected or observed global change	Increased groundwater salinization because of seawater intrusion due to climate change and aquifer overexploitation is mentioned.
Selected references	Anonymous, 2003. Risking Salinity in Thailand and Lao PDR, *Watershed, People's forum on ecology, Burma, Cambodia, Loa PDR, Thailand Vietnam*, Vol. 9(1), pp. 12-25 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=china, consulted at October 2008 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=thailand, consulted at October 2008 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=vietnam, consulted at October 2008 Fedra, K., Winkelbauer, L. and V.R. Pantulu, 1991. Environmental Problems of Water Resources Development in the Lower Mekong Basin, Ch 4 in Expert Systems for Environmental Screening, An Application in the Lower Mekong Basin,RR-91-19, International Institute for Applied Systems Analysis, A-236l, Laxenburg, Austria, Wannakomol, A., 2005. Soil and Groundwater Salinization Problems in the Khorat Plateau, NE Thailand - Integrated Study of Remote Sensing, Geophysical and Field Data, PhD-thesis, Freien Universität Berlin Weng, H.X., Ma X.W., Cheng Q., Jiao J.J. and Y.C. Qin, 2005. Genetic relation between Holocene transgression and chemical composition of the shallow groundwater in Hangzhou, China, *Environmental Geology*, Vol. 47, pp. 1111–1119 Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Australia & Pacific

Global Groundwater Region 34: Western Australia	
Countries included	Australia
Generalized hydrogeological setting	This region includes low to moderate elevated, predominantly flat basement blocks of Australian Craton, separated by deep sedimentary basins. Sedimentary basins contain thick layers of sandstones and karstified limestone and local alluvial sediments. Climate is semi-arid to arid.

	Main physiographic units or geological provinces: a) Pilbara Block b) Yilgarn Basement Block c) Carnavon Basin d) Canning Basin e) Officer Basins f) Eucla Basin g) Kimberly Basement Block h) Musgrave Basement Block i) McArthur Basin j) Wiso and Georgina Basins Groundwater resources are low to moderate. Groundwater in crystalline and volcanic rocks is restricted to local pockets of fractured and weathered zones or shallow layers of alluvial sediments. Fissured sandstones (e.g. Canning Basin) and limestone (e.g. Eucla Basin) form large regional aquifers. The amount of renewable groundwater is small in comparison to the total storage. Palaeochannel sands (representing former riverbeds) are also prospective aquifers in the region, though the groundwater salinity is high.
Adequacy of information accessed on saline groundwater	The salinity problem in Australia is well studied and documented. There is a strong focus on dryland salinity. The vastness and remoteness of the country inhibit a full coverage with detailed salinization information.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* Groundwater salinization is a widespread phenomenon in this region. Dryland salinity, groundwater salinity associated with closed basins and irrigation are the main genetic types found in this zone. Though subsurface salts are present in various geological formations over vast areas, the relationship with groundwater salinity is not well understood. The low-lying coastal area around the city of Darwin (Joseph Bonaparte Gulf, Van Diemen Gulf) (304) has many tidal flats and tidal creeks. *Incidental flooding, especially during cyclonic storms* (A3) of these areas resulted in shallow groundwater salinization. In about the whole of the karstified Cape Range peninsula in the West of Australia saline groundwater is found at shallow depths. This is caused by naturally occurring seawater wedges under the land surface (A4). Larges areas in Australia are prone to dryland salinization (B5). Over the past 100,000 years, salts have been accumulating in the top soil (about 30 kg of salts per hectare) over large areas in Australia. This salt accumulation was created by the process of tropic seawater evaporation, windborne transportation and subsequent precipitation. After human settlement a few hundreds of years ago, the natural vegetation of trees in Australia was often removed and replaced by agricultural land. Groundwater replenishment increased due to this land use change. Consequently, groundwater tables rose in many parts of the country *dissolving the accumulated* salts. Dryland salinity is found in the Avon Wheatbelt area and in the Western and Eastern Mallees.

	A large number of playas or saline lakes are found in the Western part of Australia (e.g. Lake disappointment (305) , Lake Mackay (306), Lake Percival (307) and Lake Amadeus (308)). In these closed basins surface water ponds and groundwater drains. *Evaporation of the lake water* enriches the lake salinity. Often the groundwater draining in these lakes already contains high TDS since it *dissolves salts on* its way (B1/C1) . (B2). Evaporates and other salt-bearing formations are found in the Amadeus (309), Officer (310), Georgina (311), Carnavon (312 and 313)and Canning basins (314). These deposits vary from Pre-Cambrian to Permian age. At this moment, it is unclear how groundwater in these basins is affected by the presence of the salt-bearing layers. Intensive irrigation in the Avon wheatbelt (315) and Eastern Mallee (316) caused *water logging and input of brackish groundwater* at various locations resulting in shallow groundwater salinization (C1).
Current or potential threats of saline groundwater to the interests of society or ecosystems	Dryland salinity and irrigation induced salinity are considered as big threats for the agricultural production, water resources, infrastructure (salt destroys bitumen and concrete) and biodiversity.
Current or potential opportunities of saline groundwater to the interests of society or ecosystems	The hypersaline groundwater found in Palaeochannel aquifers in the Eastern Goldfields Region in SW Australia is abstracted for gold ore treatment.
Human responses to threats and or opportunities(management)	Dryland salinity and other types of salinity management are well developed in Australia and include research and monitoring, awareness raising, policy development and implementation of prevention, remediation and adaptation measures. Measures include designing of new farming systems that management water and salt balances, use of advanced irrigation and draining technologies, land use change and crop (salt-tolerant) change, reforestation, saline aquaculture, flood gates in tidal creeks and aquifer storage and recharge schemes.
Impact of expected or observed global change	
Selected references	Andrew A.S., Whitford, D.J., Berry, M.D., Barclay, S.A. and A.M., Giblin, 2005.Origin of salinity in produced waters from the Palm Valley gas field, Northern Territory, Australia, *Applied Geochemistry*, Vol. 20, pp. 727–74 Arakel, A.V. , Jacobson, G., and W.B. Lyons, 1990. Sediment-water interaction as a control on geochemical evolution of playa lake systems in the Australian arid interior, *Hydrobiologia*, Vol. 197, pp. 1-12 Conacher, A.J., Salt of the Earth, Secondary Salinization in the Australian Wheatbelt, *Environment*, Vol. 32(6), pp 4-42 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=australia, consulted at October 2008 National Heritage Thrust, Dryland Salinity in Australia, A Summary of the National Land and Water Resources Audits, Australian Dryland Salinity Assessment 2000 Salama, R.B., Otto C.J. and R.W. Fitzpatrick, 1999. Contributions of

	groundwater conditions to soil and water salinization, *Hydrogeology Journal*, Vol. 7, pp.46–64 Timms, B.V., 2005. Salt lakes in Australia: present problems and prognosis for the future, *Hydrobiologia*, Vol. 552, pp1–15 Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Global Groundwater Region 35: Eastern Australia	
Countries included	Australia
Generalized hydrogeological setting	This region includes low to moderate elevated, flat areas of East Australian sedimentary basins. The older consolidated sediments are frequently overlaid by extensive alluvial fans. Uplifted areas in the Eastern margin (Great Dividing Range), belonging to the Tasman Mobile Belt, are also included. Climate is arid to semi-arid. Main physiographic units or geological provinces: a) Gawler Ranges b) Great Artesian Basin c) Murray Basin d) Great Dividing Range e) Australian Alps f) Tasmania Island Groundwater resources are moderate to high. Thick layers of sandstones form one of the world's largest aquifer systems (The Great Artesian Basin Aquifer System). Fissured limestone aquifers also occur (e.g. Murray Group Aquifer). Extensive alluvial aquifers, associated with the large rivers draining the uplifted areas, are important shallow groundwater source. Uplifted areas themselves have only local aquifers found in the fractured rocks.
Adequacy of information accessed on saline groundwater	The salinity problem in Australia is well studied and documented with a strong focus on dryland salinity. The vastness and remoteness of the country inhibit a full coverage with detailed salinization information.
Main occurrences, origin and dimensions of shallow saline groundwater	*General picture:* Groundwater salinization is a widespread phenomenon in this region. Dryland salinity, groundwater salinity associated with closed basins and irrigation are the main genetic types found in this zone. Though subsurface salts are present in various geological formations over vast areas, the relationship with groundwater salinity is not well understood. In the Burdekin delta (317), Pioneer valley and Bundaberg valley (318) at the East coast of Australia, coastal groundwater exploitation for irrigation purposes and decreased surface water runoff have lead to *lateral seawater intrusion* (A4) (Larges areas in Australia are prone to dryland salinization (B2). Over the past 100,000 years, salts have been accumulating in the top soil (about 30 kg of salts per hectare) over large areas in Australia. This salt accumulation was created by the process of tropic seawater evaporation, windborne transportation and subsequent precipitation.

	After human settlement a few hundreds years ago, the natural vegetation of trees in Australia was often removed and replaced by agricultural land. Groundwater replenishment increased due to this land use change. Consequently, groundwater tables rose in many parts of the country *dissolving the accumulated* salts. Dryland salinity in East Australia is found at the Northeastern coast of Queensland (319) and especially in the Murray Darling basin in New South Wales (320). A large number of playas or saline lakes are found in the Eastern part of Australia (e.g. Lake Eyre (321), Lake Gairdner (322), Lake Torrens (323) and Lake Frome(324)). In these closed basins surface water ponds and groundwater drains. *Evaporation of the* lake water enriches the lake salinity (B1). Often the groundwater draining in these lakes already contains high TDS since it *dissolves salts* on its way (B2). Evaporates and other salt-bearing formations are found in the Adavale basins (325). At this moment, it is unclear how groundwater in these basins is affected by the presence of the salt-bearing layers. *Intensive irrigation* in the Murray Darling basin (Murrumbidgee Irrigation Area) and NE coastal valleys and deltas caused water logging and input of brackish groundwater at various locations resulting in increased groundwater salinization (C1) (326).
Current or potential threats of saline groundwater to the interests of society or ecosystems	Dryland salinity and irrigation induced salinity are considered as big threats for the agricultural production, water resources, infrastructure (salt destroys bitumen and concrete) and biodiversity.
Current or potential opportunities of saline groundwater to the interests of society or ecosystems	
Human responses to threats and or opportunities(management)	Dryland salinity and other types of salinity management are well developed in Australia and include research and monitoring, awareness raising, policy development and implementation of prevention, remediation and adaptation measures. Measures include designing of new farming systems that management water and salt balances, use of advanced irrigation and draining technologies, land use change and crop (salt-tolerant) change, reforestation, saline aquaculture, flood gates in tidal creeks, artificial recharge and aquifer storage and recovery schemes.
Impact of expected or observed global change	
Selected references	Arakel, A.V., Jacobson, G., and W.B. Lyons, 1990. Sediment-water interaction as a control on geochemical evolution of playa lake systems in the Australian arid interior, *Hydrobiologia*, Vol. 197, pp. 1-12 FAO AGL, 2000. http://www.fao.org/ag/agl/agll/spush/degrad.asp?country=australia, consulted at October 2008 Leaney, F.W., Herczeg, A.L. and G.R. Walker, 2000. Salinization of a Fresh Palaeo-Groundwater Resource by Enhanced Recharge, *Ground water*, Vol. 41, pp. 84-92

	National Heritage Thrust, 2000. Dryland Salinity in Australia, A Summary of the National Land and Water Resources Audits, Australian Dryland Salinity Assessment 2000 Rengasamy, P., 2006, World salinization with emphasis on Australia, *Journal of Experimental Botany*, Vol. 57(5), pp. 1017–1023 Salama, R.B., Otto C.J. and R.W. Fitzpatrick, 1999. Contributions of groundwater conditions to soil and water salinization, *Hydrogeology Journal,* Vol. 7, pp.46–64 Timms, B.V., 2005. Salt lakes in Australia: present problems and prognosis for the future, *Hydrobiologia*, Vol. 552, pp1–15 Werner, A.D. and M.R.Gallagher, 2006. Characterisation of sea-water intrusion in the Pioneer Valley, Australia using hydrochemistry and three-dimensional numerical modelling, *Hydrogeology Journal*, Vol. 14, pp. 1452–1469 Williams, J., Walker, G.R. and T.J. Hatton, 2002, Dryland Salinization: a Challenge for Land and Water Management in the Australian Landscape, Ch 21 in *Agriculture, Hydrology and Water Quality*, (eds) Haygart, P.M. and S.C. Jarvis, CAB International Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and their use, IHP-VI series on groundwater, Vol. 6

Global Groundwater Region 36: Islands of the Pacific	
Countries included	New Zealand, New Caledonia (France), Solomon Islands, Federated States of Micronesia, Vanuatu, Tuvalu, Kiribati, Fiji, Tonga, Samoa, French Polynesia, Marshall Islands (USA), Northern Marianas (USA), Hawaiian Islands (USA)
Generalized hydrogeological setting	This region includes small islands of South-Eastern Pacific and New Zealand, belonging to of Circum-Pacific Belt. Pacific islands West of the American continents are also included. The region has large variation in elevation and relief. Volcanic rocks are found in the Northern part. The Southern part (New Zealand) includes also crystalline rocks, uplifted by the orogeny, and thick sequences of sedimentary rocks. Climate is humid. Main physiographic units or geological provinces: g) Bismarck -New Hebrides Volcanic Arcs h) Fiji Island i) Orogenic belt of New Caledonia j) Axial tectonic belt of New Zealand k) Sedimentary basins of New Zealand l) Pacific islands West of the American continents Groundwater resources are variable. Some recent volcanic rocks are highly porous and contain large volume of water. Karstified limestone and porous calcareous formations in coastal areas are also important aquifers. Shallow aquifers occur in unconsolidated alluvial sediments. Fresh water lenses are usually shallow and saline water intrusions are very common.
Adequacy of information accessed on saline groundwater	Limited information available for most Pacific Islands

Main occurrences, origin and dimensions of shallow saline groundwater	*General picture*: Groundwater salinity in this global region is related to the geographical setting: relatively small islands in volcanic active areas. The humid climate provides sufficient runoff to create shallow fresh water lenses on top of brackish and saline groundwater. Some of the Pacific islands are located in the cyclonic area (about 10-20˚ Southern latitude) and typhoon area (about 10-20˚ Northern latitude) (142). High tides during these storms can lead to *incidental sea flooding on low-lying coastal parts* of Pacific islands and especially the low-lying atolls (A3). Lateral seawater intrusion under atoll islands is often illustratively used in textbooks. The high shoreline length /surface area ratio and the often small groundwater storage capacity of these islands make them very susceptible for seawater intrusion due to groundwater abstraction (A4). Groundwater is mostly pumped for domestic purposes and subsistence farming. Recently groundwater use by the tourist sector has aggravated the salinization situation on some islands. On New Zealand, saltwater intrusion is found in the Poverty Bay area and Hawke Bay A4) (327 and 328). Most of the islands in the Pacific and the Northern part of New Zealand have a volcanic origin. Active *hydrothermal systems with associated high TDS-contents* are found on numerous of these islands (B4) (329 to 333).
Current or potential threats of saline groundwater to the interests of society or ecosystems	On many of the Pacific islands, people are heavily dependent on groundwater resources for their drinking water and other uses. Surface water is often lacking or has highly variable water availability and quality.
Current or potential opportunities of saline groundwater to the interests of society or ecosystems	Hydrothermal systems are used for heat and other energy generation (New- Zealand, Hawaii) and touristic and medical purposes.
Human responses to threats and or opportunities(management)	On many Pacific countries experiencing groundwater salinization due to groundwater pumping, remedial measures as water use saving, wastewater re-use and artificial recharge are practiced. Some major tourist resorts on the tropical islands use desalinization plants.
Impact of expected or observed global change	The effects of sea level rise on low-lying atoll countries is often used in the climatic change discourse
Selected references	Barnett J. and W. N. Adger, 2003. Climate Dangers and Atoll Counties, *Climatic Change*, Vol. 61, pp. 321–337 Ministry for the Environment, Government of New Zealand, 2007. Groundwater Quality in New Zealand State and Trends 1995–2006 Whitea, I., Falkland, T., Metutera, T., Metai, E., Overmars M., Perez, P. and A. Dray, 2007. Climatic and Human Influences on Groundwater in Low Atolls, *Vadose Zone Journal*, Vol. 6, pp.581-590 Williams, J., Walker, G.R. and T.J. Hatton, 2002, Dryland Salinization: a Challenge for Land and Water Management in the Australian Landscape, Ch 21 in *Agriculture, Hydrology and Water Quality*, (eds) Haygart, P.M. and S.C. Jarvis, CAB International Zektser, I.S. and L.G. Everett, 2004. Groundwater resources of the world and

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Annex 3: Table of saline groundwater bodies

#	Name	Global Groundwater Region	Salinity code
1	Gulf Islands Aquifer System on Canadian West Coast	1	A4
2	Northern Coast of San Francisco Bay	1	A4
3	Monterrey Bay	1	A4
4	Baja California	1	A4
5	Noroeste Province, Gulf of California	1	A4
6	Guatemala coast	1	A0
7	Costa Rica	1	A0
8	Northern coast of Gulf of California	1	C1
9	High Plains in USA and the Great Plains of Canada	1	B5
10	Cuencas Centrales del Norte, Mexico	2	D0
11	Coastal plain region of USA, various aquifer systems	5	A1
12	Biscaine aquifer system in Florida	5	A4
13	Bahamas, Cap Haitien, Port au Prince and Gonaives, Haiti	5	A4
14	Yucatan, Mexico, irrigation and relict brackish groundwater of marine origin	5	D0
15	Northern coast of Falcon, Venezuela	6	A4
16	Western coast of Lake Maracaibo, Venezuela	6	A4
17	Guajira, Colombia, also partly of B1/B2 origin	6	A4
18	Antioquia, Colombia	6	A4
19	Provinces of Esmeraldas, Manabi and Guayas, Ecuador	6	A0
20	Tumbes-Piuara zone, Northern Peru	6	A0
21	Salar de Pintados, Central Depression, Northern Chile	6	B5
22	Salar Grande, Central Depression, Northern Chile	6	B5
23	Salar de Llamara, Central Depression, Northern Chile	6	B5
24	Lago, Coipasa, Bolivia	6	B1
25	Salar, de Uyuni, Bolivia	6	B1
26	Salar de Atacama, Chile	6	B1
27	Salina Grandes, Argentina	6	B1
28	Salar de Arizaro, Argentina	6	B1
29	Salar de Antofalla, Argentina	6	B1
30	Salar de Empexa, Bolivia, Chile	6	B1
31	Salar de Ollague, Salar, Porcos, Bolivai, Chile	6	B1
32	Rio Saladi, Central Depression, Northern Chile	6	B5
33	Salar de Tara, Palmeque Grande, Chile	6	B1
34	Salina Olaroz, Argentina	6	B1
35	Salar de Pocitos, Argentina	6	B1
36	Salar near Mina la Casualidad, Argentina	6	B1
37	Small salar in Andes, Bolivia	6	B1
38	Small salar in Andes, Chile	6	B1

39	Salar de Hombre Muerto, Argentina	6	B1
40	Salar de Incahausi, Argentina	6	B1
41	Salar near Pedernales, Chile	6	B1
42	Salar de Marlounga, Chile	6	B1
43	Small salar in Andes, Argentina	6	B1
44	Salinas Grandes south of Santiago de Estero, salt flats along Rio Salado, Argentina	6	B1
45	East coast, Southern Patagonia, Argentina	7	D0
46	Connate water originated from Miocene marine transgression (Mar Enterriano or Mar Paranense)	7	A1
47	Mar del Plata, Argentina	7	A4
48	Guyana	8	A4
49	connate water originated from Miocene marine transgression (Amazonian Sea)	9	B1
50	Postglacial transgressions of the Baltic Sea	10	A2
51	Seawater intrusion in Cretaceous Alnarps aquifer (limestone) in Scania, Southern Sweden	10	A4
52	Ireland	10	A4
53	Infiltration of seawater into geothermal systems in Reykyavic Peninsula	10	B4
54	Intrusion Mediterranean Sea Coast	10	B2
55	North Sea basin	11	A0
56	Zone of salt tectonics related to the former Permian Zechstein Sea,	11	B2
57	Permian salt domes, city of Perm, Solikamsk, Orenburg, Russia	11	B2
58	Lower-Permian salt strata in Severnaya Dvina artesian basin, Russia	11	B2
59	Northern shores of the Black Sea	11	D0
60	Astrakhan Lakes, Kazachstan	11	B1
61	Turkmenistan desert (Kara Kum)	11	B5
62	Connate saline groundwater and intruded seawater and climatic features along shore Caspian Sea	11	A1
63	Almeria, Spain	12	A4
64	Barcelona, Spain	12	A4
65	Golfo San Jorge, Spain	12	A4
66	Cagliari, Italy	12	A4
67	Piombino, Italy	12	A4
68	Rosignano Solvay, Italy	12	A4
69	Ancona region, Italy	12	A4
70	Po-delta, Italy	12	A4
71	Naples area, Italy	12	A4
72	Palermo area, Sicily, Italy	12	A4
73	Eastern coast of Sicily, Italy	12	A4
74	Reggio di Calabria, Italy	12	A4
75	Apulia region, Italy	12	A4
76	Vieste, Manfredonia, Lago di Varano, Lago di Lesina, Italy	12	A4
77	Po delta, Italy	12	A7
78	Lesvos Island, Greece	12	A4
79	Chios island, Greece	12	A4
80	Athens region, Greece	12	A4
81	Gulf of Argolikos Kolpos, Greece	12	A4

82	Iraklion region, Crete, Greece	12	A4
83	Cap Gata, Cyprus	12	A4
84	Cap Greco, Cyprus	12	A4
85	Cap Pomos, Cyprus	12	A4
86	Agadir area, Morocco	13	A4
87	Rabat area, Morocco	13	A4
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112	Coast of Mozambique	16	A4
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149	city of Iloil, Philippineso	23	A4
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