Sustainable Groundwater Management
Lessons from Practice

Case Profile Collection Number 16

Promoting Management of an Inter-State Aquifer under Development for Irrigated Agriculture – the Chapada do Apodi in North-East Brazil

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This case profile summarizes the progress made by the Secretaria de Recursos Hídricos (SRH)-Ceará (with support from GW•MATE during 2002-05) in promoting management of the groundwater resources of the Chapada do Apodi Aquifer System, which is experiencing a rapid growth in demand for the extension of commercial irrigated agriculture. The fact that this aquifer system is of inter-state distribution required liaison and collaboration with neighboring Rio Grande do Norte – and the celebration of 'La Oficina sobre Gestão Integrada do Aqüífero Jandaíra entre os Estados do Rio Grande do Norte e Ceará' (Mossoró : 11 November 2004) was something of a first at Brazil's national level. The longer-term aim of the Inter-State Working Group will be assimilation of the results of on going groundwater investigation and monitoring, defining concept notes for any necessary additional work, and providing coordinated advice periodically to SRH-CE and SERHID-RN on resource management and source protection strategy.

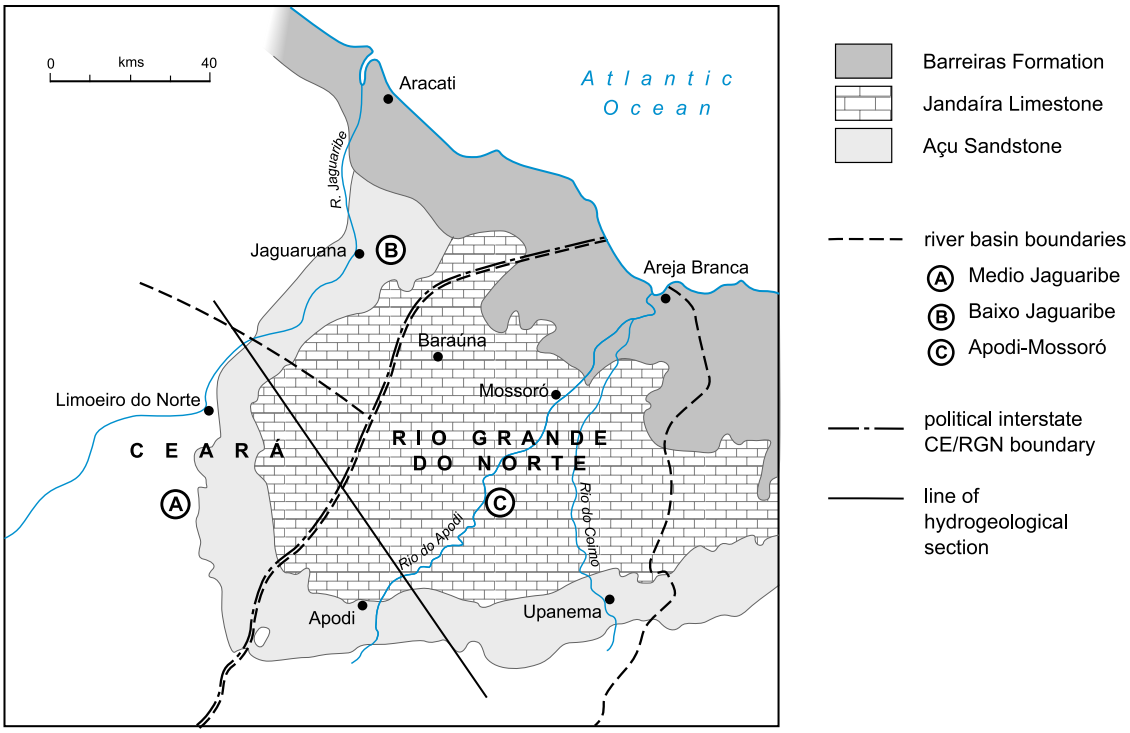
CHAPADA DO APODI – GEOHYDROLOGICAL SETTING

Nature of Aquifer System

- The Chapada do Apodi is an extensive plateau at about 80-140 meters above sea level, delimited by the valley of the Jaguaribe river to the west and extending beyond the Apodi river to the east (Figure 1) – falling about 35% in Ceará and 65% in Rio Grande do Norte, and situated remote from the respective state capitals of Fortaleza and Natal. It possesses a major aquifer system – called here the Apodi Aquifer System – comprising the Jandaíra Limestone (which widely forms the land surface) and the underlying Açu Sandstone.

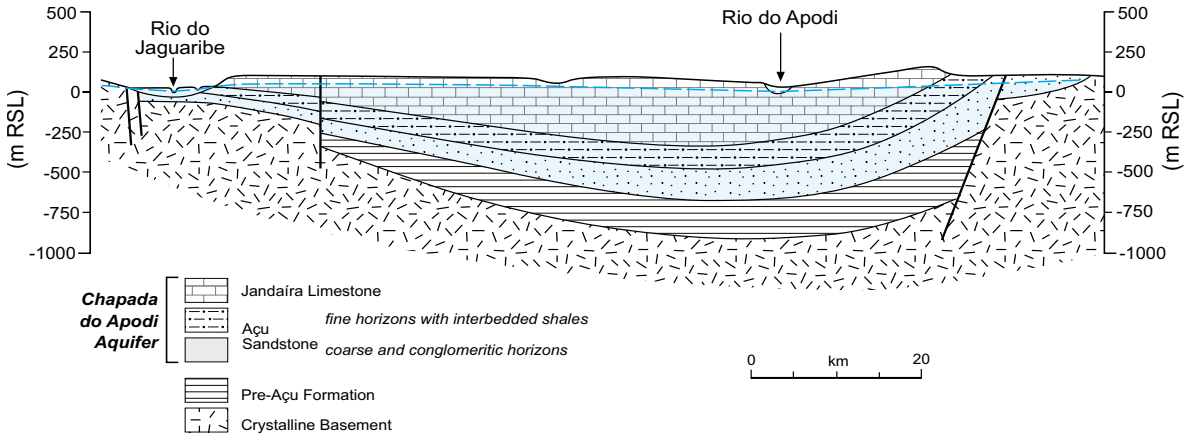
- The geological structure containing this aquifer system is known geologically as the Potiguar Basin, which extends a long way eastwards in Rio Grande do Norte beyond the area under present consideration. This is a partly-faulted depression in the Pre-Cambrian crystalline shield, which has experienced both continental and marine deposition with many sea-level transgressions and regressions since Middle Cretaceous times.

Figure 1: Extension of the Chapada do Apodi Aquifer System



- The Jandaíra Limestone thus exhibits rapid lateral variation of sedimentary facies, and includes both massive karstified limestones (including features at the land surface) and horizons of bioclastic calcareous deposits with much less cementation, and also has zones with much more marly aspect and relatively poor groundwater potential (such variations having been mapped through electrical resistivity profiling). The overall formation totals up to 200 m in thickness (Figure 2) and aquifer transmissivity varies widely between 50-1000 m^2/d. The aquifer generally provides wells of 60-150 m depth with yields of 10-200 m^3/hr of groundwater whose total dissolved solids (TDS) are in the range 1700-1900 mg/l, with predominant calcium bicarbonate giving some encrustation problems in irrigation systems.

Figure 2: Hydrogeological section of the Chapada do Apodi

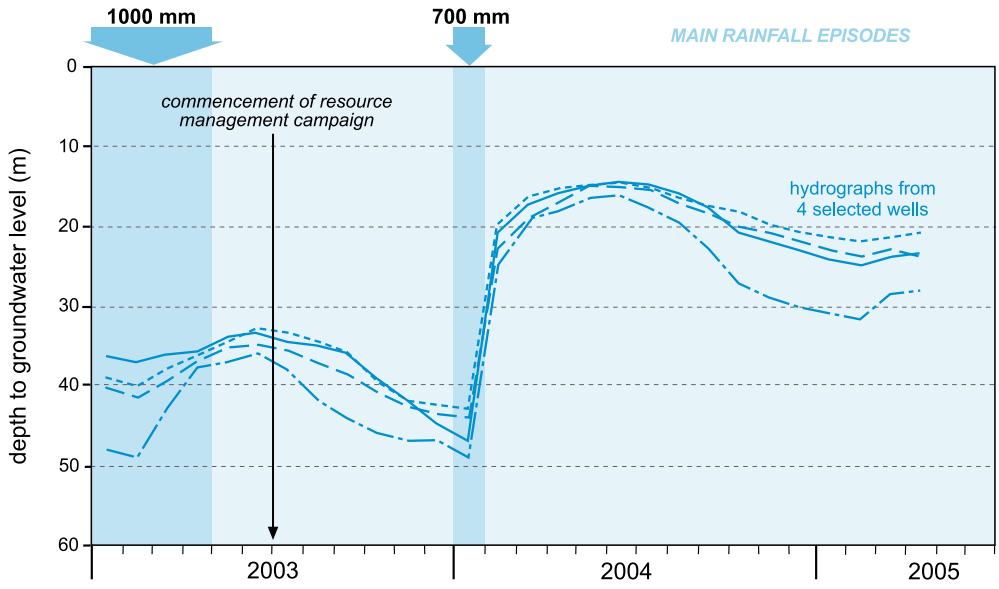


- The limestone is separated from the underlying Açu Sandstone by a transitional aquitard of up to 20 m thickness, and they apparently exhibit a variable leaky hydraulic relationship. The Açu formation is a weakly-cemented fluvial sandstone, with some interbedded silts and calcareous accretions, which has a thickness of 20-200 m and an aquifer transmissivity of 25-350 m2/d. It provides well yields of up to 100 m^3/hr of good quality groundwater with TDS of only 750-950 mg/l. Well depths to tap the Açu Sandstone are moderate in the outcrop area (100 m), but increase markedly on the limestone plateau to 300-1,000 m, especially in the vicinity of Mossoró where its groundwater also has geothermal potential.

Groundwater Recharge & Flow Regime

- The average rainfall of 700-900 mm/a is mostly concentrated during February-April and can fall at high intensities, but is accompanied by very high potential evaporation (in excess of 2,000 mm/a). The sources of aquifer replenishment are:
  - intense rainfall, excess to short-term plant requirements, over the extensive outcrop area of the aquifers – a graphic illustration of this occurred in January-February 2004 when an exceptional rainfall episode (totalling more than 700 mm in less than 20 days) resulted in a recovery of groundwater levels by around 25 m (Figure 3) at some locations
  - the possibility of some riverbed recharge occurring along parts of the alluvial tracts of the Jaguaribe river into the Açu Sandstone (along the western flank of the aquifer system) and along the Apodi River to both the Açu Sandstone and Jandaíra Limestone – but in both cases these rivers could equally act as local discharge sinks for part of the aquifer system
  - in addition (and most significantly) surface water irrigation returns (via canal/ reservoir losses and excess field application) from the Jaguaribe-Apodi transfer scheme (constructed in 1987), which pumps some 43 Mm^3/a (2,500 l/s) of river water onto the Chapada do Apodi to irrigate an area of around 3,000 ha – although a program of primary/secondary reservoir and canal lining during 2004, and increasingly efficient irrigation systems will have substantially reduced this source of recharge.

Figure 3: Groundwater level hydrographs in Baraúna—Rio Grande do Norte during 2003-04 illustrating recharge effect from exceptional rainfall episode



- There has been little systematic groundwater investigation, except for a regional reconnaissance survey by IPT-São Paulo in 1988. Groundwater piezometric measurements have not been made over a sufficiently large area to determine with confidence the groundwater flow directions in the Jandaíra Limestone, although it is suspected that much of the flow following major recharge incidents will be directed generally north-eastward towards the lower part of the Apodi Valley and the Atlantic Ocean, perhaps rapidly along preferential karstic pathways.

- Nor are there adequate measurements to define the hydraulic relation between the Jandaíra Limestone and the Açu Sandstone (often separated by an aquitard). Early groundwater level observations suggest an initially confined deep aquifer with artesian heads in the Mossoró area (that may have been caused by gas entrapment), but on pumping these declined rapidly and leakage is probably induced from the overlying Jandaíra Limestone.

GROUNDWATER RESOURCE DEVELOPMENT

Current Groundwater Utilization

- In Ceará no up-to-date full water well inventory exists, while in Rio Grande do Norte the area around Baraúna (Figure 1) has been recently subject to an intensive campaign of data collection. Elsewhere only patchy information is available. The main types of use of groundwater appear to be:
  - major commercial irrigation schemes (mainly melon, papaya, pineapple, mangos, bananas and other tropical fruits) for both the export and national market
  - public water supply for the towns of the area, including part of Mossoró (total population approaching 500,000) and many smaller settlements
  - supply to rural small-holdings for domestic use, livestock watering for low-density ranching and occasional irrigation of cashew trees.

- Groundwater has been tapped progressively over decades for town water supply and for isolated farm smallholdings, but the large-scale exploitation of the Jandaíra Limestone for irrigation of commercialized tropical fruit production is a phenomena of the last 5-10 years, and an indication of this development is given in Table 1.

Table 1: Scale of groundwater development for commercial irrigated agriculture on the Chapada do Apodi

PARAMETER	CEARÁ	RIO GRANDE DO NORTE (Baraúna area only)
No of Water Wells	some 234 water wells of 30-150 m depth known, but only part of these in use for irrigated agriculture	100 exploratory irrigation water wells were drilled in 1997 with a further 500 added subsequently in an area of some 400 km^2 (but 140-180 for domestic and livestock use only)
Groundwater Extraction for Irrigation	60-70 licensed irrigation wells with a combined capacity of around 700 l/s – but this perhaps represents only 40% of total due to illegal water well drilling	some 300 active irrigation wells (typically 40-100 m deep) producing 30-100 m^3/hr from a water table usually at 20-25 m depth
Land Area under Irrigated Agriculture	2,600 ha (using pressurized tubes with micro-aspersion) of which 1,140 ha have licensed groundwater supply plus some 3,000 ha irrigated by surface water transfer	comprises 42 large-scale commercial irrigators occupying 2,900 ha and a further 198 smaller producers with a total of some 1,100 ha

- The cost of development of infrastructure for commercial agriculture (including irrigation technology and groundwater supply provision) is said to be around (Brasil) Rs 25,000/ha (US$ 9,100/ha), and thus the private capital investment in groundwater-based commercial fruit growing on the Chapada do Apodi (whose overall extension is believed to exceed 7,500 ha) has probably reached (Brasil) Rs 190 million (US$ 70 million), and demand is still believed to be rising.

Sustainable Development — Issues & Needs

- If agricultural development is to be sustainable, there is a pressing need to:
  - define the sustainable limit on groundwater resource use and implement the necessary constraints on abstraction through local water resource administration arrangements
  - determine the risk of groundwater pollution by agrochemicals (especially pesticides) and to implement controls adequate to protect potable groundwater supplies in the area.

- Both should be evaluated by SRH-CE and SERHID-RN on a coordinated basis, especially bearing in mind that the area tends to act as a single socio-economic unit. Aquifer management and source protection will require a step-wise approach, with interim policy being established following an initial diagnosis and then subsequent refinement through analysis of the results of longer-term monitoring (say 5 years later). This, in turn, implies further investment in monitoring groundwater use, levels and quality as an essential step.

Table 2: Priority topics for further investigation to underpin groundwater resource management and protection policy

PRIORITY TOPIC	DETAILED SCOPE	RECOMMENDED MECHANISM
Understanding of Aquifer Flow Regime & Storage Characteristics	groundwater flow directions, recharge/discharge mechanisms and relations with Jaguaribe + Apodi Rivers, and (given its part karstic character) the capacity of aquifer system for storing groundwater on inter-annual/longer-term basis	directly from interim results of main SRH-CE consultancy contract and comparison of SERHID-RN analysis/ monitoring
Evaluation of Aquifer Recharge Rates & Available Resources	assessment of amounts and periodicity of rainfall recharge, to reach conclusion about resource availability based on average recharge rates and storage behaviour of groundwater reservoir	as above (but specific briefing needs to be given to consultant in this regard)
Mapping of Irrigated Agricultural Cropping	delineation of existing irrigated areas (differentiating groundwater and surface water use), present irrigation technology/efficiency and cropping regime	should be available or commissioned from corresponding state agricultural organization
Economic Potential for Groundwater Development	review of economics of groundwater use in commercial irrigated agriculture and the factors influencing future trends (including land availability with adequate soil characteristics, markets for products grown, and sources of investment in agricultural infrastructure)	requires a supplementary consultancy to be let with local agronomist and agricultural economist
Assessment of Groundwater Pollution Hazard	evaluation of risk of groundwater pollution by agrochemicals and its implications for the protection of drinking water sources – including the ability of local government to establish a degree of land-use control in their immediate vicinity	for SRH-CE all relevant data should be collected by main consultancy contract (briefing of consultant needed) but the assessment of land-use control powers and the extrapolation of results to RN may require specialist services

- There are a number of priority topics which require further evaluation to provide a sound basis for the definition of an inter-state policy on agricultural development using groundwater (Table 2), and the preferred mechanism by which to undertake the proposed work is also indicated. In the longer run, the development of a joint SRH-CE/SERHID-RN aquifer numerical model will be required (together with an agreed long-term plan for monitoring groundwater use, levels and quality) as an essential basis for refining and communicating groundwater resource estimates and management needs.

APPROACH TO GROUNDWATER MANAGEMENT

Legal Framework

- According to the Brazilian Constitution (1988), water resources fall in the public domain. Whilst surface water resources are considered to be either federal or state property, depending on whether river concerned crosses state boundaries, all groundwater resources (except 'mineral waters') are within the domain of the corresponding state.

- The Constitution provides for states to legislate in respect of water resources, environmental protection and pollution control. Both Ceará and Rio Grande do Norte issued their water laws (respectively 5 years and 6 months) before the national water law was approved, and subsequently both states have developed substantial related secondary legislation (Table 3).

- A comparative review of existing water resources legislation and corresponding implementation impediments, together with the institutional arrangements which impinge on groundwater management, is underway to aid social understanding and identify any areas which require strengthening. This has to include the need for possible powers over the use and handling of agricultural chemicals, and the need for special municipal land-use controls to protect drinking water sources.

Table 3: Groundwater management and protection topics included in state primary and secondary water resources legislation

TOPIC	CEARÁ		RIO GRANDE DO NORTE	
	Primary	Secondary	Primary	Secondary
Planning & Allocation	•	+	•	
Integrated Water Management	•	+	•	
Extraction Permits	•	+++	•	+
Resource Protection & Conservation		++	•	
Institutional Powers & Coordination	•	++	•	++
Stakeholder Participation	•	+	•	+
Information Systems	•	+		
Economic Tools	•	++++	•	+
Law Enforcement	•	+		+

primary legislation = legislative material incorporated in an Act of the State Legislature
secondary legislation = legislative material (rules, orders, decrees, by-laws, etc) issued by State Executive ++++ increasing degree of evolution

Institutional Arrangements

- Both states have developed substantially their water resources management institutions (Table 4), and although their main priority historically has been surface water the focus recently has moved to groundwater. In addition both states have river basin committees (CBHs – Comitês de Bacia Hidrográfica) to approve river basin plans and promote understanding among stakeholders.

- Since 1994 Ceará has had an executive agency (COGERH) in charge of water resource management implementation, while Rio Grande do Norte has only recently established a similar agency (IGARN).

- Specifically for the Chapada do Apodi Aquifer System, the current institutional arrangements for groundwater resource management and protection in both Ceará and Rio Grande do Norte are summarized in Figure 4, which also indicates how they might best interact.

Table 4: Organizations responsible for facets of the state-level integrated water resources management system (SIGERH)

MAJOR FUNCTIONS	ORGANIZATION CE	RN
committee coordinating water resources policy	CONERH	CONERH
agency promoting IWRM and managing linkages between water-sector organizations	SRH	SERHID
agency responsible for water resources management implementation	COGERH	IGARN
financial fund for water resource plan implementation	FUNORH	FUNERH

Recent Groundwater Management Actions

- In the RN-Baraúna area intensive development of groundwater for commercial irrigated agriculture, compounded by lack of management, had caused the water table to fall to 30-50 m bgl by late 2002 (Figure 3) (despite rainfall close to the normal average), causing concern amongst users about sustainability of their investment. In response to these stakeholder concerns, SERHID undertook an imaginative and intensive social awareness campaign and:
  - declared an emergency area for groundwater resource conservation, with interim suspension of further well drilling (except for human and animal consumption) in April 2003, subject to review following more local monitoring of resource behavior
  - required re-licensing of all water wells, and imposed as conditions the installation of access tubes for groundwater level monitoring and of use meters to enable the estimation of actual water production, with remarkable user cooperation.
  - water levels recovered early in 2004 (Figure 3) following exceptional precipitation (700 mm) during January – February and with more effective aquifer management

- On the Ceará side, progress has been made on charging a 'resource fee' for groundwater abstraction for commercial irrigated agriculture (ranging from US$ 0.001- 0.003 /m^3) – but it is recognized that charging alone will not be enough to regulate usage, since water supply represents only a very small proportion of the total production cost of irrigated agriculture.

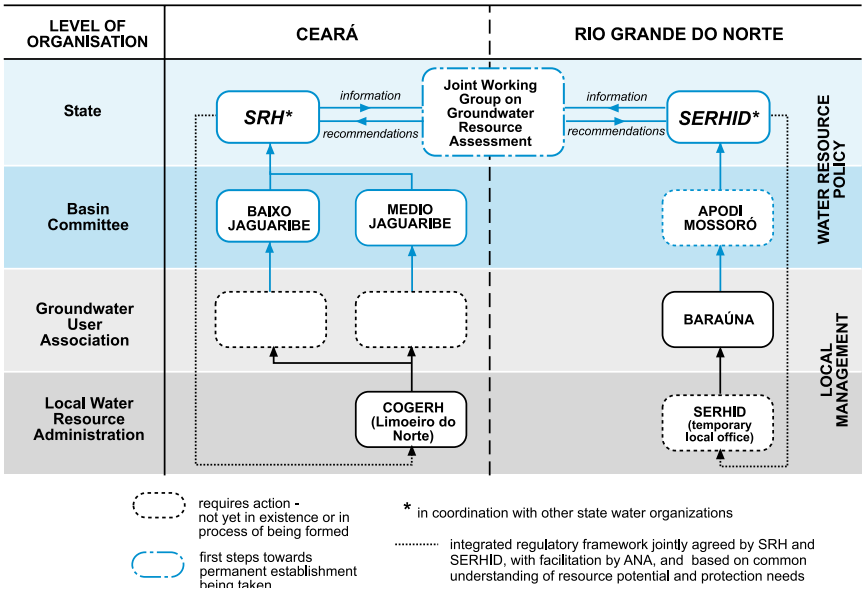
Inter-State Action on Shared Aquifer System

- To ensure the sustainable development and adequate protection of groundwater resources a 'twin-track approach' was strongly advocated in which:
  - a small Inter-State Working Group on Groundwater Management (GTIEGAS) is established, as recommended by the 1st CE-RN Groundwater Resource Meeting (1a Oficina sobre Gestão Integrada do Aqüífero Jandaíra entre os Estados do Rio Grande do Norte e Ceará) in Mossoró on 11 November 2004, with the aim of assimilating the results of on-going groundwater investigation/monitoring, defining concept notes for additional work as necessary, and providing coordinated advice periodically to SRH-CE and SERHID-RN on resource management strategy
  - the framework for local water resource administration/management is appraised and developed through formation of 'groundwater user associations' (to facilitate user participation), under the umbrella of the various

'Comitês de Bacia' (River Basin Committees), and consolidating the emplacement of fully effective local groundwater resource administration offices (eg. COGERH—Limoeiro do Norte in the case of Ceará).

- Given the high political will for inter-state cooperation, the enthusiasm and rapport of both technical teams, and the useful management experience in both states, both of the above actions can and should be taken soon. This should be conceived of as paving the way for the agreement of a plan of shared and integrated groundwater resource management.

Figure 4: Summary of institutional arrangements for groundwater resource management and protection for the Chapada do Apodi aquifer system



- Once the CE groundwater resource groundwater consultancy is generating relevant data on resource availability, the GTIEGAS should be in a position to produce a preliminary coordinated groundwater resources strategy for SRH-CE and SERHID-RN. At this time it will probably be necessary to approach Federal Government (ANA) to authorise an Inter-State Regulatory Agreement for the management of the shared aquifer system, comprising some form of 'minimum reference framework' in terms of shared information systems, agreed priority uses, constraints on development and approach to protection.

- An on-going experience of inter-state surface water management between Rio Grande do Norte and Paraíba to manage the Curema-Açu System, sanctioned by an agreement where ANA (Agência Nacional de Águas) plays an important role, will certainly prove valuable when promoting the required Ceará-Rio Grande do Norte inter-state groundwater management agreement.

Publication Arrangements

The GW•MATE Case Profile Series is published by the World Bank, Washington D.C., USA. It is also available in electronic form on the World Bank water resources website (www.worldbank.org/gwmate) and the Global Water Partnership website (www.gwpforum.org).

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