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IMWA INSIGHTS

Renewed Demands for Mine Water Management

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Abstract The intensity and diversity of resource development projects has increased by orders of magnitude over the past two decades. At the same time, there has been an emphasis on environmental issues, decontamination of former industrial sites, a recognition of global warming issues, and a focus on the ability of project developers to initiate, operate, and close transient projects without compromising the land and water resource values that underpin existing and future land uses. This concurrence of issues is creating a massive demand for hydrogeologists and groundwater engineers throughout the world. Neither academic institutions nor their funding bodies have foreseen this demand. As a consequence, Australia is seeking to fill its demands by either temporary or permanent importation of skills but, since the same issues afflict other countries, or may come to do so in the near future, the Australian approach will probably be only marginally successful. Another issue confronting all countries active in groundwater management is that the range of skills now required for competent groundwater management around resource development projects have increased. These cannot be readily met by simply increasing the training load on new industry entrants. Rather, delegation of expertise will be necessary and management teams will need to include diverse professions in teams in order to cover the range of responsibilities that must be applied if sustainable decisions are to be made. The authors believe that there is an urgent need for groundwater managers to take up the learning opportunities and expand their skills by working even more internationally. This process should ensure cross fertilization of experience to the benefit of all the countries where groundwater issues are taken seriously.

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Introduction

General Observations

Through 50 years of consulting on resource development projects and 20 years of academic involvement, the authors have seen the depth and size of mines and the need for thorough mine water management increase. In addition, coal seam and shale gas harvesting, carbon sequestration, and in situ gasification now place an increased responsibility on groundwater professionals. Communities are concerned that many of these projects will have major social and environmental impacts. Consequently, the mitigation of these impacts and community concerns has, in the authors' opinion, changed the required skills and employment prospects for groundwater professionals.

In the past, mine water related work for groundwater professionals has been subject to uncertainties because of the cyclical ("boom and bust") nature of the mineral and energy industries. Those cycles have flattened and the continuous increase in membership numbers in the International Mine Water Association (IMWA) since 1997 proves this! This paper will mostly focus on the demand for groundwater professionals in Australia, but Australia is just a case study, since other regions in the world face similar issues. European and Canadian perspectives complement this Australian perception.

Coal

As an example, the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) expects world exports in coal to grow from 773 Mt in 2005 to 897 Mt in 2025 (Fairhead et al. 2006). Similarly, the Bureau for Resources and Energy Economics statistics for 2011 showed Australian production to have increased from 274.9 Mt in 2003 to 353.0 Mt in 2010. This makes Australia the largest single coal exporter in the world; its exports represented nearly 28 % of the total world hard coal exports in 2010 (sum of metallurgical and thermal coal; BREE 2011). Australian coal exports are reported by ABARES as growing from 233 Mt in 2005 to between 353 and 435 Mt in 2025 (Fairhead et al. 2006e). In economic terms, the value derived from Australian coal exports has varied. Figure 1 shows how return variations of the Australian Dollar (AUD) reflect both varying demand in the international coal market and coal price. This is not reflected in coal production statistics or in the employment of human resources involved in productive mining.

Growth in the future will be associated with the opening of new mines, especially in Queensland and New South Wales, India, China, and South America. There will also be continued growth of existing open pit mines with attendant increases in water management issues therein and with increasing needs for coal beneficiation as lower-grade coals are won. Several reports have emphasized the criticality of mine water management in sustaining peripheral and post mine closure land productivity and in mitigating downstream water quality and value (e.g. Australian National Water Commission 2010, 2011).

Iron Ore

Iron is another major Australian mineral export commodity which has grown from an annual value of 15.5 billion AUD in 2005 to 49.5 billion AUD in 2010 (IBIS Business Research 2011). This represents a growth rate of 10.4 % per annum, with the export tonnages expected to double again by 2020. Continued increases in iron ore exports will be achieved by the opening of new mines in the Pilbara Region of Western Australia and in many other areas where iron ore provinces are known to exist in Western Australia and in South Australia. The major export markets are China, Japan, and Korea (Fig. 2).

In both iron ore and coal mining, the water issues are extremely varied and relate to desaturation and depressurization to ease geotechnical problems and a wide range of environmental and resource preservation issues.

Supply and Demand

Australia and Brazil are major sources of minerals and energy. Yet, the demand for these commodities, as exemplified by China's steel industry's demand for iron ore (Fig. 2), is such that new resource projects cannot be brought on line fast enough to meet the market demand or to moderate commodity price levels for any extended period. Resource supply and demand balance will develop in the long term as new resources are found, especially on

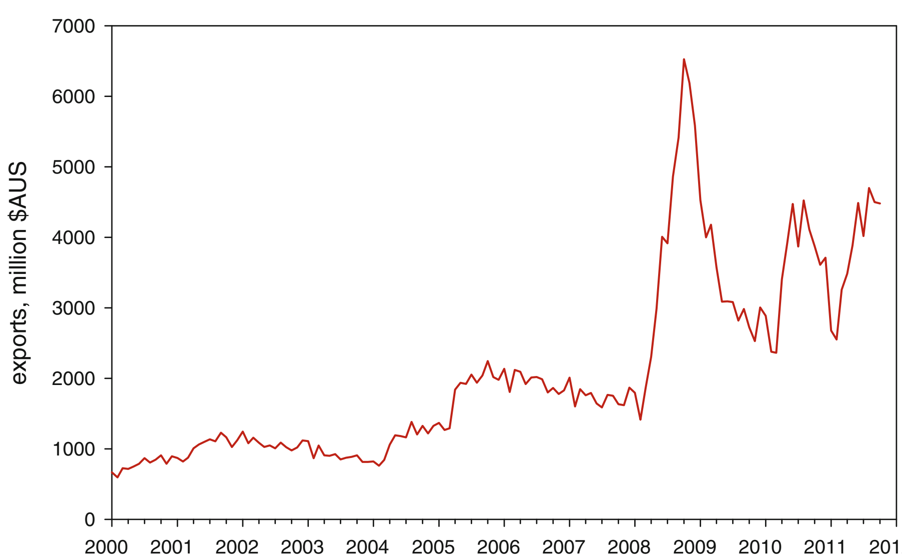

Fig. 1 Australian Coal, Coke and Briquettes Exports (Australian Bureau of Statistics, Catalogue no 5368.0 International Trade in Goods and Services, Australia, table 12a. merchandise exports, Standard International Trade Classification [1 and 2 digit], FOB Value)

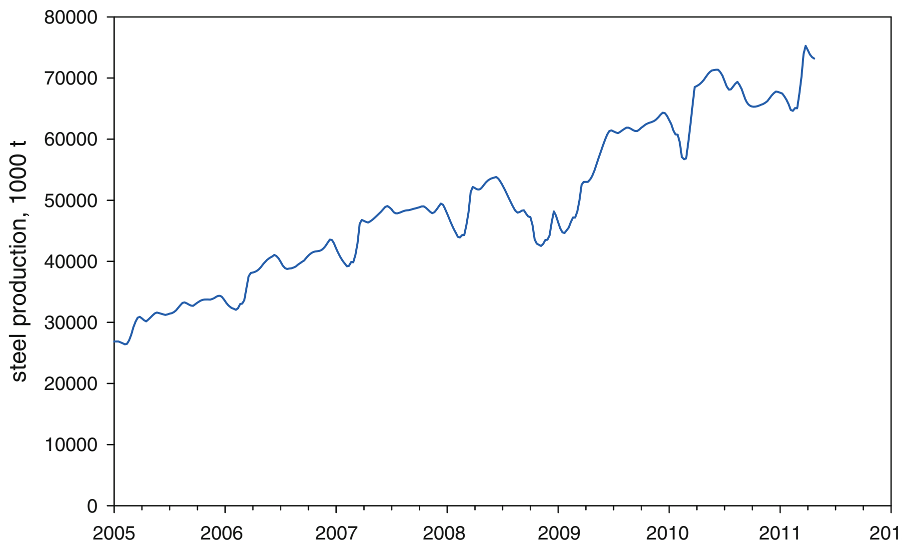

Fig. 2 China finished steel production (China Metallurgical Newsletter)

the South American and African continents. Exploration into potential new mines must involve at least the following:

- infill drilling work must be done to define the resources to meet internationally accepted ore reserve calculation standards;
- in some countries, sovereign risk and triple bottom line impediments must be identified, including the demands of the Equator Principles (International Finance Corporation—Performance Standards and World Bank EHS Guidelines), which are increasingly being used as a prerequisite for project financing by institutions of projects that exceed $10 million U.S. (Conley and Williams 2011; Equator Principles Association 2006).
- all new resource development projects, and indeed, project expansions, will be subject to societal and governmental approvals within the context of emerging climate change and sustainability paradigms.

This work increasingly requires rigorous analysis of project impacts, including the need for groundwater management plans to minimize and mitigate hydrogeological and geochemical impacts during the project's operational life and post closure such that future alternative land use choices are not compromised. All of these issues require that groundwater management teams be more extensively skilled and larger in number than in the past. Meeting these personnel demands is very difficult in most countries because professional training facilities have not foreseen the burgeoning need and the skilled staff are simply not available. As such, staffing significantly constrains resource project development.

While the mineral industry can still be expected to be cyclical to some extent, the substantially increased demand for mineral resources from developing economies such as Brazil, Russia, India, and China ("BRIC" nations) has extended the length of the cycles between highs and lows in mineral and energy prices (Fig. 3a–c). This has greatly increased the demand for professionals with groundwater development and management skills. In fact, the market for such skills has never been better!

Academic Training for Groundwater Specialists in Australia and Germany

Groundwater specialist training in Australia has, to some degree, been incorporated in undergraduate Bachelor courses in earth sciences and, to a lesser extent, in civil, mining, and geological engineering since the late 1980s. More comprehensive training has been available in Honours (Minerals Tertiary Education Council 2012) and Master's degree courses with the most effective skills being developed in Masters Courses involving course work and a minor thesis. A few candidates have proceeded to Doctorates and, through the research skills learned, these people have generally proven to be valuable groundwater practitioners, especially when the thesis was focused on groundwater issues. In most European countries, hydrogeology is a scientific study. Before the Bologna process was enacted, hydrogeologists got their comprehensive training in the last 2 years of their 5–6 years Diploma study. In the meantime, hydrogeology is taught as a Master Course, which usually needs a geology or environmental Bachelor degree as a prerequisite.

Data on the number of people graduating at any degree level in Australia with skills fitting them for a career applying groundwater/hydrochemical technology are very limited. The Minerals Council of Australia (MCA) has documented only 1,700 four year graduates in Earth

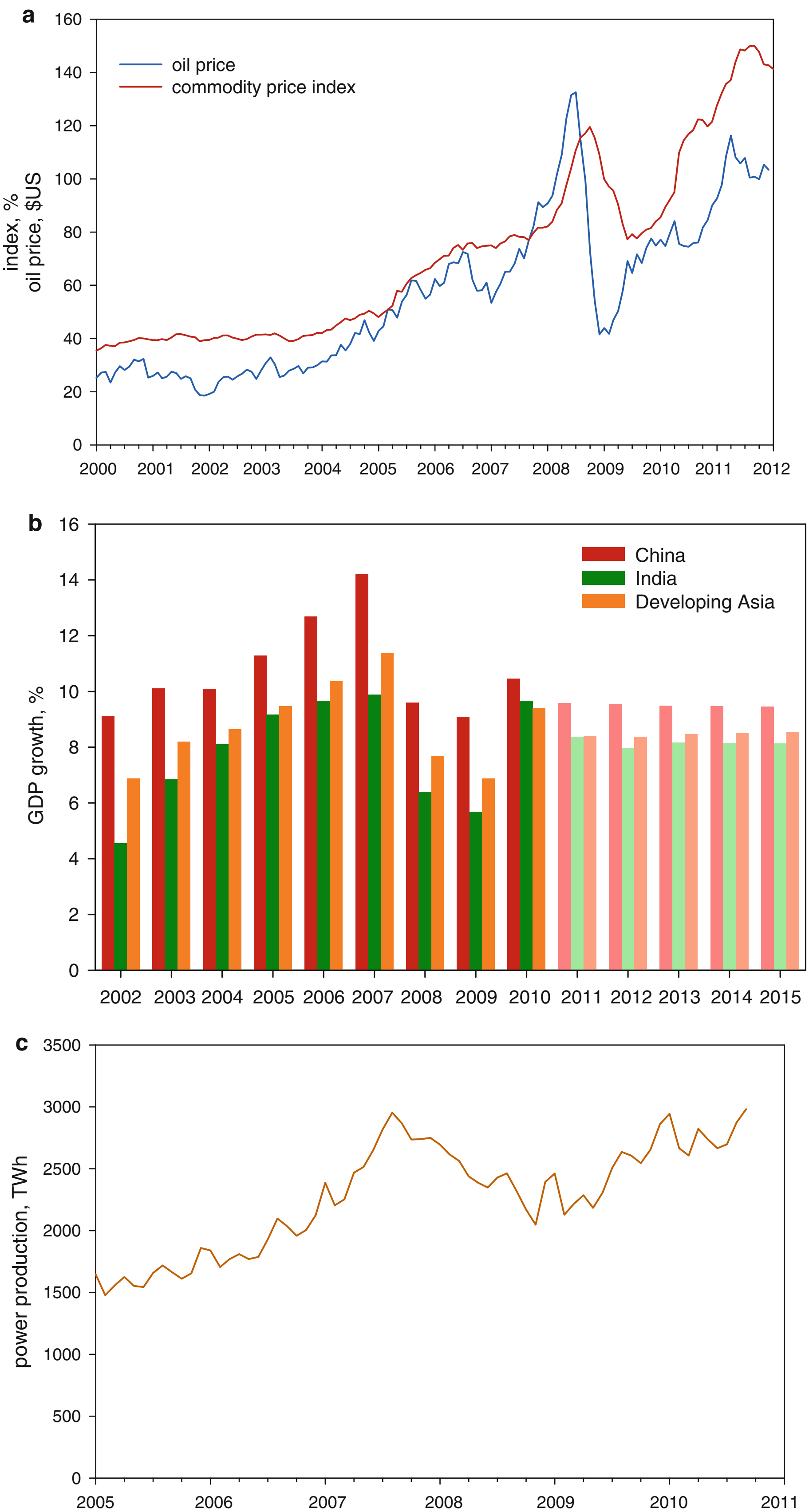

Fig. 3 **a** Commodity versus Oil Prices (IMF Primary Commodity Prices, International Monetary Fund, G5 RBA Index of Commodity Prices). **b** Asian GDP Growth Projections (International Monetary Fund, World Economic Outlook Database, October 2010). **c** Chinese Thermal Power Production (China Statistics Bureau; E.L.& C. Baillieu Stockbroking Ltd—I. Reis: Outlook for 2010)

Science since 2000. Relatively few of these graduates have become hydrogeologists. A survey of URS (URS Australia Pty Ltd) hydrogeologists who had graduated over the period between 1985 and 2005 revealed that only about 10 % of 4 year graduates went on to focus on groundwater studies. Data from other universities (personal communication, Jeff Webb, Latrobe University 2011) confirmed this estimate with about 180 graduates at various levels from four universities in Victoria qualified through with at least a sub-major in groundwater hydrology between 2000 and 2011.

In addition to earth science graduates focusing on groundwater, a proportion of environmental science and engineering graduates have also focused on groundwater. These graduates have been increasing in number since 2000. Their undergraduate training has been supplemented by generic but comprehensive introductory training delivered through the government-funded Australian Groundwater Schools, which are run each year by the National Centre for Groundwater Research and Training (NCGRT). The schools are bridge courses aimed at bringing together the various source disciplines that contribute to groundwater management in Australia.

Because of the enormous demand for earth scientists in the mining and environmental fields, a number of graduates have taken up employment with only a 3 year degree. Industry sources, such as the MCA, comment that these graduates are not adequately trained to be able to perform the tasks for which they are employed. This situation is aggravated by the fact that the senior personnel within mining companies are overloaded with work. Consequently, they do not have the time to provide the supervision and training-on-the-job which such graduates need.

A further disturbing trend was also noted by MCA; the number of 4 year graduates in earth sciences and mining engineering is very likely to plateau beyond 2015. Advice from academic institutions, such as the NCGRT (established in 2009), indicates that less than 60 students with groundwater skills graduated from all of the training institutions in Australia in 1990 (personal communication, Jeff Webb 2011). By 2000, it is estimated that the number of graduates in the country had only risen to about 100. Thereafter, the number of graduates pursuing careers directed towards groundwater has increased, with a focus on environmental studies. Melbourne University (personal communication, Charles R. Lawrence, University of Melbourne 2011) reports that there are presently about 90 students there undertaking undergraduate degrees that include some element of groundwater training. Other universities have lesser numbers of students involved in similar studies. There are also some engineers who will move into groundwater modelling and groundwater management. But if the annual total number of graduates from these courses is about 300–400 (Minerals Tertiary Education Council 2011), this will likely only translate to about 40 new graduates per annum focusing on a career in groundwater technology. Of these, only about 45 % will take employment within the mining companies or with consultants or contractors servicing the mining and resource development industries.

Unfortunately, no data is available on the number of Australian graduates who are educated and specialized in groundwater issues. Yet, it is obvious that the number of new entrants to the mining industry is critically below the levels necessary to sustain the needs of the mining industry in such a water challenged nation such as Australia. The lack of graduates with significant training in groundwater technology is especially serious when the internationally burgeoning demands of the mining and energy resource development industries are considered.

Furthermore, training institutions which seek only to cover local market demands are delinquent in their responsibility to both their graduates and to the internationally oriented industries of Australia. This is especially serious for the mining and energy resource companies of Australia. A very great demand exists, and is developing, worldwide for competent groundwater specialists, and Australian institutions and resource companies can be major partners in meeting this demand.

Germany has 30 universities with a focus on geology and 20 of those offer curricula that allow the study of hydrogeology. Of those 20, only the universities in Freiberg, Aachen, Bochum, Greifswald, and Dresden regularly offer theses in the mining sector. No German university currently offers courses that specialise the students in mine water hydrology. Until about 20 years ago, four German Universities (Aachen, Berlin, Clausthal, and Freiberg) offered full curricula for mining engineers that included basic courses about mine water, mainly focusing on dewatering or pumps. Now, future mining engineers can only study in Aachen, Clausthal, and Freiberg. Three German universities (Bochum, Freiburg, Darmstadt) offer full curricula for geothermal studies, though most universities with a geological focus at least offer courses about geothermal energy.

Groundwater Employment Demand Growth

Traditional Mining

Professionally qualified groundwater specialists have serviced Australian resource development projects, mostly as consultants or as regulators, for only about 50 years. Similar employment regimes have applied for a little longer in North America and even longer in Europe. The services involved locating and licensing water supplies, undertaking and implementing dewatering/depressurization facilities, and evaluating likely environmental and geotechnical consequences of the developments.

Employment of groundwater professionals in Australia in 1980 is not documented, but would have been no more than 250–300 mostly self-taught geologists or engineers. Implementation work was largely undertaken by mining and civil engineers, with contractors building systems that were physically robust, but frequently inadequately designed to avoid long-term environmental and social problems. An example of such problems occurred at Bougainville in Papua New Guinea (Cornish 2010), where co-disposal of acidic drainage from the mine, tailings, and waste rock from a base metal mine decimated the environment of a local river and nearby reef fish breeding areas. This was highly detrimental to both the environment and to the food sources of the indigenous people. These issues contributed to serious social unrest, which has closed the operation for several decades.

In the European Union, the tailings dam failures of Aznalcóllar, Baia Mare, and Baia Bursa in 1998 and 2000 (e.g. Rico et al. 2008) increased concerns about potential surface or groundwater pollution in the vicinity of mine sites. This, in consequence, increased the need for environmental studies, including hydrogeological and hydrological issues. A large number or European consultants and academia were involved.

As environmental concerns developed worldwide, hydrogeological services have been required to assess the potential for contamination from mine water releases, including leakages from tailings storage facilities and, more recently, from waste rock dumps and mines. Many of these phenomena are now very well understood.

Generic skills have been developed for managing and mitigating acid mine drainage and salinity impacts. Geochemical characterization of mine wastes (aqueous and solids) is now as common in the search for synergistic mitigation of contamination issues as are hydrological and geochemical modelling. These skills serve to predict, track, and demonstrate that mitigation of contamination impacts is possible, and that the environmental footprint of mines and the long-term degradation of surrounding land and of alternative land uses can be controlled.

Ten years ago (2001), the number of groundwater professionals in Australia would have been between 400 and 450, with about 30% of these being university trained personnel with specialised skills in groundwater (mostly Master's degree obtained by course work). The number in 2011 is probably a little more than 700 in total. Many groundwater professionals have been involved in evaluation and remediation of contaminated industrial sites and in the permitting of solid waste facilities, with some drift of professionals between the two areas being common, especially within consulting companies. These environmental pursuits involved studies at a much smaller scale than those required for today's resource projects.

In the last 25 years, the regulatory regimes applied around urban solid waste management facilities have migrated into the mining and minerals processing industry. A prime example is the European Union "Mining Waste Directive" (Directive 2006/21/EC of the European Parliament and of the Council on the management of waste from the extractive industries) enforced in 2006. At the same time, increased commodity prices have justified deeper mining of lower grade ores and the development of open cut mines that extend to much greater depths and over much greater areas than in the past.

With these changes, increased mine water inflows have been experienced. Progressive mine water chemistry variations have been encountered, impacts of desaturation in addition to saline water intrusion problems have given rise to risks of ore value diminution and geotechnical instability, and subsidence of peripheral land has increased. These problems are operational threats to project viability; as a consequence, groundwater and contamination management has become a core mine management activity. Mining companies have become direct employers of professional groundwater staff.

Nearly all of the top mining companies now require internal groundwater professionals, who are backed up by consultants who add depth and experience to the mining company staff. In addition, the imposition of regulatory provisions and the consequences of infringements on mining company reputation and social license to operate are so severe that continuous internal surveillance is necessary in order to meet industry standards such as are implicit in the Mineral Council of Australia's "Enduring Values" policy, to which most mining companies are committed (Minerals Council of Australia 2005).

The groundwater professional employment consequences of the above are that there are now over 400 internally employed groundwater professionals and support technical staff in Australian mining projects. Consultants employ or are seeking to employ more than 400 similar professionals. But this is not the end of the employment demand story.

Climate Change Stimulated Projects

Coal Seam Gas Projects (Coal Bed Methane and Shale Gas)

Most recently, discussions about climate change have led to the search for sources of energy that are either largely clean of CO_2 emissions or at least provide energy resources capable of conversion to power more efficiently than from pre-existing sources such as lignite and brown coal. This has led to a rapid expansion of new projects, including those associated with coal seam and shale gas (CSG, this Australian terminology includes both coal bed methane—CBM and shale gas—SG). The development of these energy projects has been especially active in Australia (Capital Consultants Management 2011), and in the U.S., where it has developed into a multi-billion dollar industry in less than a decade (New et al. 2011, Table 1).

CSG, as an industry, grew out of petroleum engineering, but its development in Australia, the U.S., and Europe has directly interfaced with traditional pastoral and agricultural pursuits that depend for their future on the same water resources. CSG projects depressurize the target coal seams to stimulate gas flow, and so the industry is critically dependent on the availability of hydrogeological and groundwater engineering skills to maintain gas flow and economic returns.

The groundwater management required for such projects straddles the interface between the source coal seams and the aquifers overlying and underlying these. Consequently, there is a potential for impacts on the regional artesian pressures within the aquifers that underpin the economics of the pastoral industry of a large part of Australia in the Great Artesian Basin (Fig. 4). Equally, there is the perception and probability of impacts on groundwater dependent ecosystems, on indigenous heritage values, and on initiating micro-seismic events and land subsidence of potentially disturbing magnitudes.

Most of the same phenomena have also been observed around depressurization sites in Canada and elsewhere. In the case of a geothermal project in Basel/Switzerland, a 2.6–3.4 magnitude earthquake led to the temporary abandoning of the fracking process (Deichmann and Giardini 2009). The mitigation of these socially disturbing phenomena will, in large part, depend on groundwater management skills applied through drill hole orientation selections that maximize natural permeability flow paths for gas release, optimize pressure gradients to stimulate gas release, and integrate the use of managed aquifer recharge into gas flow management to mitigate unacceptable impacts. The magnitude of groundwater management intervention necessary for CSG projects currently being developed is only now coming to be understood by the operators in Australia, and is only sparingly understood by regulatory authorities.

The outcome of this "learning period" is that massively complex, restrictive, and probably unworkable licensing conditions have been imposed on CSG operators. These are generally recognized in the industry as being interim measures designed, at least in part, to allow the industry to commence while it gathers the data that will allow rational redevelopment of pre-existing groundwater uses and policies. The consequence of this complex regulatory environment is that again, there is a further increase in the demand for hydrogeological skills. Again the demand, in Australia at least, will be for hundreds of groundwater specialists. There simply are not that many available within Australia.

The magnitude of this industry at one centre in Queensland alone (Gladstone) is already in excess of 70 billion Australian Dollar (The Australian Financial Review 2011). Given our knowledge of the deep Permian coal seams within the massive Great Artesian Basin and peripheral basins (Fig. 4), the industry can only be expected to grow even further.

Similar projects are expected to develop worldwide wherever gassy coal deposits are known to exist at depths beyond which normal mining can be viable. Significant projects are being pursued in the U.S. (Fig. 5), where a 373 % production increase to 347 $\times$ 10^9 m^3 for shale gas is expected between 2009 and 2035 (U.S. Energy Information Administration 2011). Canada is also increasing production of shale gas. Projects are under development in

Table 1 Energy and mining advanced projects April 2011 (modified from New et al. 2011)

	Energy projects		Minerals projects		Minerals and energy processing		Total	
	No	Cost[a]	No	Cost[a]	No	Cost[a]	No	Cost[a]
New South Wales	8	4,202	3	2,146	–	–	11	6,348
Victoria	2	4,639	1	32	1	65	4	4,736
Queensland	13	38,204	4	1,964	2	2,644	19	42,812
Western Australia	8	67,077	24	29,172	1	2,268	33	98,517
South Australia	1	146	2	279	–	–	3	425
Tasmania	1	345	–	–	–	–	1	345
Northern Territory	2	1,340	1	0	–	–	3	1,340
Australia	35	115,953	35	33,593	4	4,977	74	154,523

[a] AUD $\times$ 10^6

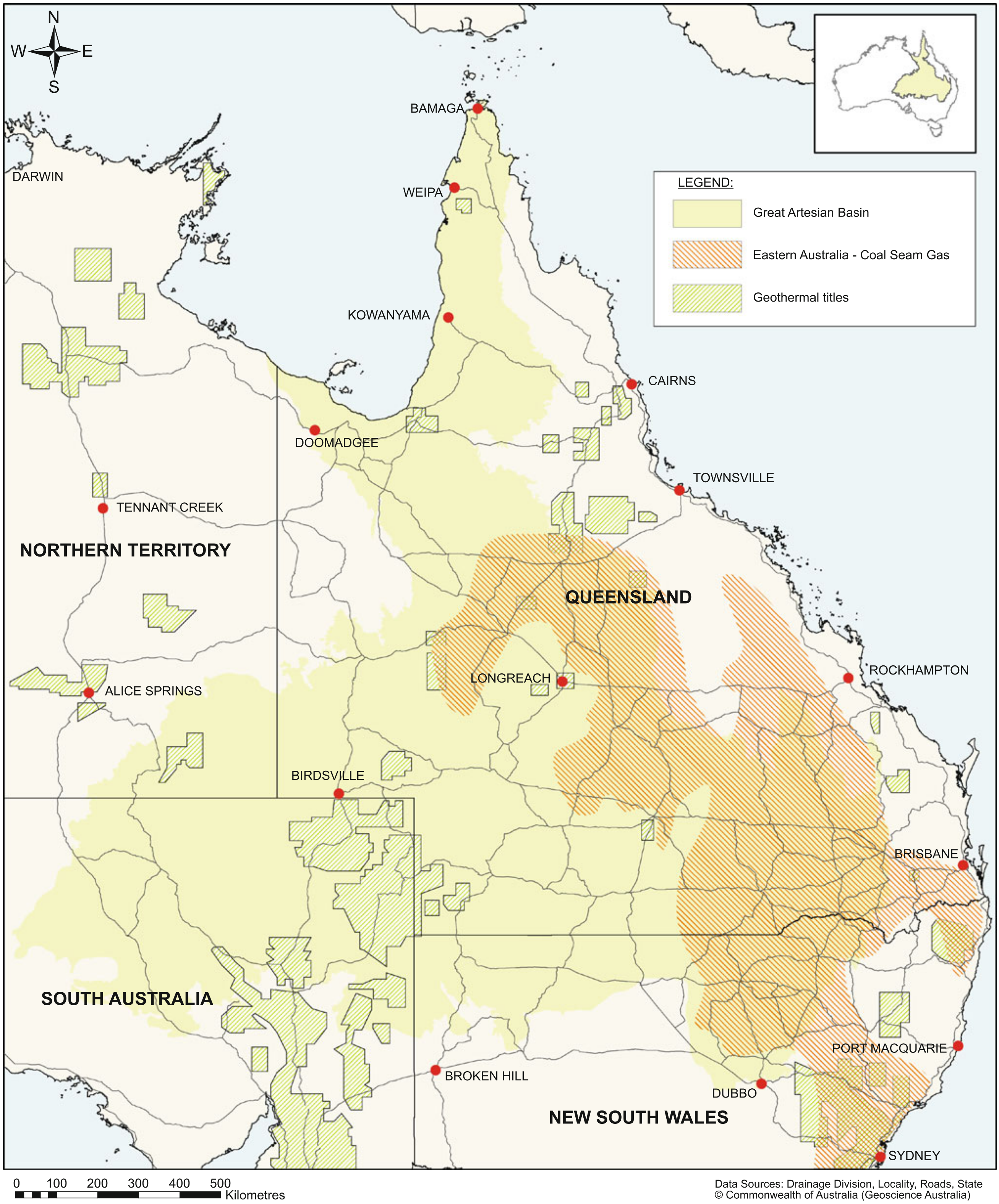

Fig. 4 The Great Artesian Basin with areas under exploration for CSG and geothermal energy shown (compiled from data using the Australian Geological Science Organization GAB Map, maps from Resource and Land Management Services: Eastern Australia Geothermal—January 2009 and Eastern Australia Coal Seam Gas—November 2011)

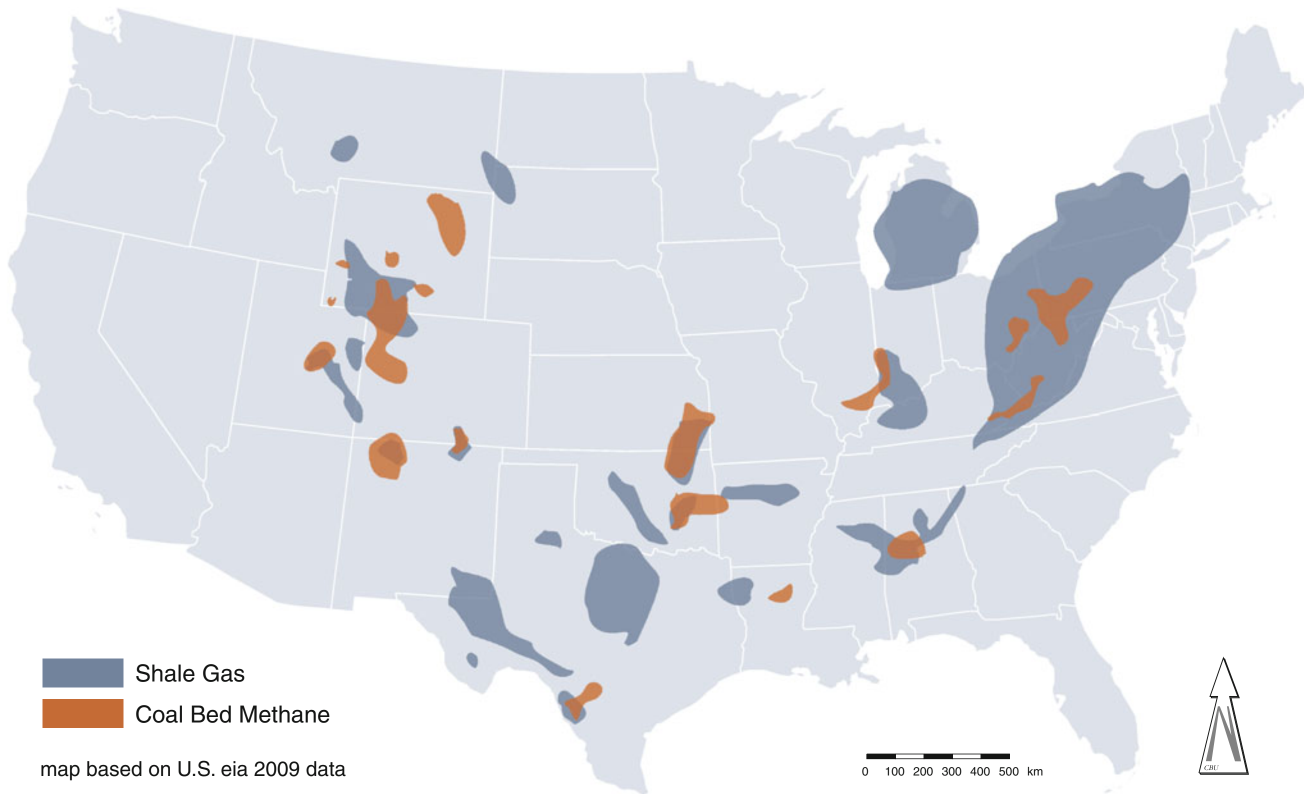

Fig. 5 Outline of U.S. coalbed methane and shale gas projects (2009 data from U.S. Energy Information Administration—EIA)

South Africa and similar interest is expected in India, China, Russia, and Europe.

CSG projects have been considered in the more densely populated parts of Europe and the UK but, to date, these have not proceeded due to social concerns related to land disruption and the frequency of micro-seismic events occurring at shallow depths (e.g. Lechtenböhmer et al. 2011; Wynn 2011). However, wherever CSG projects develop, they can be expected to confront similar problems, and their development will require substantial skills in groundwater management. Recent documentation on CSG projects in Australia by URS Australia Pty Ltd, indicate that the groundwater management operational costs will amount to more than 30 % of all operational costs. These costs include drilling, well construction, extraction, and excess water disposal. Considering the thousands of sophisticated wells needed to get the gas production volumes sought, this industry alone is likely to need more than 300 groundwater professionals either directly engaged or in consulting and regulatory roles.

Carbon Sequestration and Geothermal Energy

In response to the climate change discussion, many carbon sequestration (CS) projects are proceeding around the world, many in active or abandoned former gas provinces. Pilot trials have also commenced in Victoria, Australia; this project is using a mixed discipline team of professionals including risk evaluation, petroleum, and groundwater engineers. Incidents caused by a lack of hydrogeological or geological understanding or investigation (e.g. Kulish and Glanz 2009) will likely cause an increase in regulations. Such developments increase the demand for hydrogeological and groundwater management skills.

Similarly, considerable attention is being directed in Australia to geothermal energy sources that demand groundwater assessment and management skills along with those of well engineering. The search for clean, non-fossil fuel energy sources has stimulated a great deal of expenditure for geothermal energy from both hot wet and hot dry rock sources. Geothermal energy technology operationally involves recycling water with relatively small differential pressure change. But the initial evaluation tests involve pumping water out and back into deep aquifers over periods of months to evaluate heat transfer and energy depletion characteristics. The heat flow equations/algorithms are essentially analogous to hydrogeological algorithms. It is clear that these projects represent yet another burgeoning area of employment for groundwater professionals in drilling and testing, in evaluation, in groundwater and heat flow management, and in system closure and resource protection. Geothermal projects are also a source of community concern, again on the basis that the development might be deleterious to alternative land use options and to the existing environment. Already, some early stage projects in Australia have suffered community objections and have been the subject of regulatory concern.

Employment Demand Summary

It is clear from the foregoing that the employment prospects for groundwater professionals worldwide is going to be very extensive, especially in Australia, Northern America, and Europe where so many new projects are being developed within a sophisticated, legislatively based, albeit inexperienced regulatory environment. A survey of online-job advertisements in the mining industry in Australia alone indicated that immediate employment opportunities existed for over 100 groundwater practitioners at all levels (January 2012: "Get Hydrology Jobs" 2011). On the basis of the foreseen expansion rates in mining and energy resource projects, it would seem likely that the demand will at least double during the next 3 years. Similar increases in demand can be expected worldwide, especially as CSG projects move from exploration to project development. Similar increases will arise from regulatory authorities as they confront the magnitude of the learning curve that they have before them. However, for professionals wishing to become involved in these expanding or new technologies involving groundwater technology, a wide range of skills have to be mastered.

Skills Requirements

Management of groundwater associated with mining, CSG, and similar projects will require a wide variety of skills associated with avoidance of deleterious land subsidence, the maintenance of geochemical stability, inter-aquifer leakage and groundwater contamination, hydrostatic pressure management, managing social and community expectations and benefits, and the protection of groundwater dependent ecosystems. In addition, water treatment before disposal and brines management issues are already emerging as alternatives to managed aquifer recharge as principal management options. The skills involved in evaluating and managing these projects are so wide that teams of multi-skilled professionals with overlapping skills will be required to be adequately pursue them. This said, the team members will need to be informed and conversant with the common issues and with the technical and hydrological parameters associated with the projects in order to provide competent service to their employers and to the community. Consequently, the skills of any team involved in mining and energy resource projects will need to include at least:

- Core skills
  - An understanding of both sedimentary and structural geology and how groundwater stress can give rise to micro-seismicity and subsidence, and the consequences of stress relief interactions.
  - An understanding of the implications of water as a geotechnical element within an aquifer skeleton.
  - A thorough understanding of groundwater hydrological parameters and the phenomena associated with primary, secondary, and induced permeability.
  - A thorough understanding of the many ways in which groundwater resources relate to the community and environmental values within overlying and surface hydrological regimes.
  - Knowledge of drilling, aquifer testing technology, and aquifer stimulation (fracturing) technology and its implications in terms of contamination, inter-aquifer flow, and pressure redistribution.
  - An understanding of thermal, salinity, and gas release implications on hydrological parameter evaluation, groundwater flows, and hydraulic efficiency.
  - A good understanding of rational commonly applied water management and protective legislation and policy precepts.
  - An understanding of the role and value of reliable monitoring data and its application in hydrological and geochemical models.
  - An understanding of a range of hydrological and geochemical models and their applications, reliabilities, and weaknesses.
  - GIS applications.
- Secondary skills
  - A good understanding of well construction technology and construction materials and their susceptibility to failure under differing chemical, physical, and thermal stresses.
  - A thorough understanding of the range of beneficial uses to which groundwater of differing chemistries can be applied, including for irrigation with differing soils, ingestion by stock or wildlife, human consumption (with or without treatment), and mineral production;
  - An adequate knowledge of geochemistry to be able to recognize where and when geochemical stability (precipitation or dissolution) may be disturbed as a consequence of depressurization and gas loss or reactions involving gases entrained in either extraction or injection.

- A thorough understanding of mine water geochemistry, including the development of acid mine drainage and the geochemical processes during the mitigation of mine water problems by means of natural attenuation or manmade treatment processes.
- Basic understanding of hydrological tracer tests to investigate hydraulic parameters of soils and rocks as well as investigating the flow characteristics of surface streams.
- A thorough understanding of flow measurements in surface streams or at mine sites using different technologies and the constraints of the different methods.

Skills Acquisition and Confirmation

A considerable number of the skills required for competent hydrogeologists and groundwater engineers involved in groundwater management for mining and energy resource projects would be better developed working in teams on actual projects rather than from academic education. Interaction and mentoring by senior team members can add to the skills in a productive and practical learning environment. This experience can be gained in project development, operation, or through work in regulatory roles.

Confirmation of comprehensive skills acquisition by accredited bodies is, however, important for the skills to be recognizable in what is, or will be, a very rewarding international market for professional groundwater management specialists. To this end, it is desirable that professional institutions develop minimum generic standards that can be used to certify accreditation of international experience as mine/energy resource water specialists. The International Mine Water Association (IMWA) is currently preparing a “Mine Water Certification” for professionals working in the mine water business, based on the exceptional skills required by professionals in the mine water and the mining industry.

Minimum prerequisite standards would be a Bachelor degree or equivalent in Geology, Earth Sciences, or Civil Engineering. The degrees would have to include training in the major elements in hydrology (both surface and groundwater), geology, geochemistry, and in geotechnical engineering. Training in drilling technology, groundwater sampling and in well construction would also be valuable. The total list of prerequisites is likely to prove too extensive for 3 year degree courses. A 3 year course plus 1 year honours, or a 3 year course plus a 2 years Master’s degree by course work would seem more likely as the prerequisite requirement for future groundwater professionals. Subsequent learning should be on the job.

Confirmation of the acquisition of skills beyond the prerequisite studies should be industry based and should stand in place to underpin applications for temporary or permanent skilled emigration visas.

Conclusions

The demand for mineral and energy commodities arising from the development of hitherto underdeveloped populous nations, plus the increasing awareness of and or acceptance of the need for sustainable project development and responses to the discussion about reducing CO_2 emissions has led to a massive increase in the demand for specialists in groundwater management. This is very strongly apparent in Australia, Northern America, and Europe where existing and new mines are being developed to much greater depths below the water table than ever before and where new CSG, CS, and geothermal energy projects are being planned within complex regulatory controls. These developments demand more professionally skilled people, but the people needed must have and will need to develop skills through project exposure and involvement.

Mining and energy resource projects are developing at uneven rates around the world, but in Australia and Europe, there are many opportunities for hydrogeologists and groundwater engineers at all levels to come and learn the new skills on the job. These opportunities exist now because academic institutions worldwide and the mining and energy industry have mostly been inadequate in foreseeing the growing professional needs. They have not promoted enough careers in groundwater specialization. Consequentially, there has been little demand for education in these areas and the institutions have not been funded to generate anything like the numbers of groundwater specialists required to meet the burgeoning demands that have and continue to develop, as can be seen by the closure of hydrogeology chairs (e.g. LMU Munich, Germany).

Shortfalls in the numbers of competent groundwater specialists are known to exist in other countries. This is going to become increasingly apparent as they too seek to develop CSG and CS projects. Australia is ahead of many other countries on the learning curve in having had over a generation of large project developments in mining, energy, and geothermal projects. It is a place where professionals can gain skills and experience in these relatively new resource development projects. These skills can then be transported to other countries to cross-fertilize the competence with which such projects are developed worldwide.

It remains for our professional institutions, such as IMWA and IAH, to take up the task of identifying skills acquisition accreditation procedures. These procedures should be recognizable internationally and will stimulate the ease with which groundwater specialists can move from project to project internationally.

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