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Research article

Application of the WEAP model in strategic environmental assessment: Experiences from a case study in an arid/semi-arid area in China

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ABSTRACT

This article investigated how the use of a water resources assessment model contributed to one of the first strategic environmental assessments (SEA) conducted for arid/semi-arid regions in China. The study was based on the SEA of a coal industry development plan in Ordos, an arid/semi-arid region of northwest China, where a temporally and spatially simplified version of the WEAP (Water Evaluation And Planning System) model was applied for assessing the impact of the planned activities on local water resource system. Four scenarios were developed to simulate various alternatives using a diverse range of water utilisation measures such as irrigation efficiency, treatment and the reuse of water. The WEAP model itself was found to be a useful tool for efficient water resources assessment in SEA: 1) WEAP provides built-in simulation modules for water assessment, which improve the SEA's efficiency significantly; 2) WEAP temporally has the flexibility in both delivering information on a reasonably aggregated level by evaluating water resource on an annual time step, which fits most SEA cases, and being possible to take a finer time step analysis monthly, weekly even daily; 3) Spatially, WEAP has advantage in dealing with distributed demand sites in large spatial scale. However, although WEAP appears as a useful tool in providing support for decision-making, in this SEA case we experienced difficulty in building a feasible scenario to mitigate the impact of the proposed activities on the local water system, so that solution had to be found outside of the assessed scenarios - which led to the discussion on the fact that the proposed activities in SEA cases are rarely regarded as an uncertainty. Therefore future research on the scope of SEA scenarios could be valuable.

1. Introduction

Strategic environmental assessment (SEA) is an important step towards the achievement of sustainable development. SEA is carried out in order to inform decision-making, so that a high level of environmental protection can be reached (Donnelly et al., 2007). SEA is a systematic process of evaluating the environmental consequences of a proposed policy, plan or programme (PPP) to ensure that the consequences are fully elucidated in order to address them appropriately at the earliest stage possible (Lee and Walsh, 1992; Thérivel et al., 1992; Sadler and Verheem, 1996). Not only environmental considerations form part of the exercise, but also social and economic perspectives, in order to underline that it is not only environmental considerations that matter, but also sustainability in a broader sense (Chaker et al., 2006; Gao et al., 2014; Kørnøv and Thissen, 2000; Partidário, 2000; Stoeglehner et al., 2009; Thérivel, 2004, p.84–89). In China, the need to consider environmental factors earlier in the decision-making process has been recognised by experts and officials since the 1990s (Bao et al., 2004). SEA as a decision making tool in China has also drawn more discussion and study by the academic community within the last decade (Gao et al., 2017; Wu et al., 2011; Zhu et al., 2010, 2011).

Water is an important natural resource and rapid industrialisation often causing serious conflicts between water supply and demand. Water scarcity and conflicts between demand and supply are caused by rapid population growth, unsustainable economic growth and massive urbanisation (Bao and Fang, 2007) and climate change (Larsen and Kørnøv, 2009). Water scarcity will eventually restrict industrialisation and social and economic development,

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meaning that water may one day constrain the world's development (Kojiri et al., 2008). A general conflict exists between the water used for households, agriculture and industrial demands on one side, and the vitality of ecosystems on the other. Studies show that in China, the “putting economic development first” ethos is still prevalent in many local administrations (Lam et al., 2009). In China, policies have far transferred large amounts of water from the natural ecosystem to industry (Fang et al., 2007; Yang, 2003), thus resulting in environmental deterioration. Against this background, it is highly relevant that SEA addresses water resource assessment and thus providing decision-makers with relevant information on how to adopt appropriate tools for water resource management.

Research shows that an environmental model could assist water resource managers in communicating with stakeholders about different policy options (Stave, 2003). Studies exist on the use of integrated water resource management model with scenario analysis in China (Guo et al., 2001). The main objective of this study is to take a SEA for a regional industry development plan in a typical arid/semi-arid area in China as a case study, to test the effectiveness of the WEAP (Water Evaluation And Planning System) model as a potential tool in assessing the impact of proposed activities on local water resource system within a SEA.

2. WEAP model

The WEAP model developed by the Stockholm Environment Institute (SEI) is designed to examine alternative water management strategies based on the principle of water balance accounting, together with demand priorities and supply preferences (Yates et al., 2005a). Some previous versions aimed to integrate natural watershed processes with socio-economic elements, including the governance of the allocation of available water supplies (Yates et al., 2005b). As a forecasting tool, WEAP simulates water demand, supply, flows and storage, and it also includes the generation, treatment and discharge of pollution. As a policy analysis tool, WEAP can evaluate a range of water management options, taking into account multiple and competing uses of water. Its applications generally include the following aspects:

- Set up of time step, area boundaries and water resource system structure;
- Water demand, resources, supply and treatment analysis;
- Scenarios design (involving future policies, costs and techniques);
- Scenarios evaluation of the water distribution and supply sufficiency.

Demand and supply analysis is the starting point for WEAP. Demand is based on disaggregated accounting for social and economic activities using a hierarchical structure, providing flexibility in the data structure from highly disaggregated to highly aggregated data. Typically, a structure consists of sectors which may be broken down further into different subsectors. The model also includes end-use characterised by the water demand in different locations, in industry processes or using different irrigation techniques. Supply concerns the availability and allocation of supplies, such as groundwater, reservoirs and other resources e.g. transfers, rivers and inflows to rivers. Return flows (e.g. wastewater to treatment plants, rivers and groundwater) will contribute to the sources when they are discharged into rivers, groundwater or other supply sources (SEI, 2008).

2.1. Recent applications of WEAP

During the last decades, the WEAP model has been used in watershed management worldwide (SEI, 2008). As early as 1992, the WEAP model was applied in simulation of water supply and demand in the Aral Sea Region in Russia (Raskin et al., 1992). As an integrated model, it has been applied mostly in water resource planning at a regional, local or basin scale (Demertzi et al., 2014; Huber-Lee et al., 2004; Groves et al., 2008; Purkey et al., 2008; Yates et al., 2009). In 2003 Levite et al. made the first attempt to apply WEAP in water allocation in a water-stressed river basin in South Africa. The study simulated diverse climatic situations and valued the model as a useful tool for rapid assessment of water allocation. They emphasised the availability and reliability of data and credible alternatives and pointed to the limitation in capturing the large variability of hydrologic phenomena caused by extreme conditions. Gaiser et al. (2008) analysed a range of existing water quality models and found WEAP provides a highly detailed and comprehensive model of water catchment and river systems and helps planning authorities to assess the long-term impact of demographic and economic development. Since 2008, the model has been adjusted and tested in Central Asia and West Africa under very different ecological, hydrological and socio-economic conditions. The results showed WEAP held potential for the simulation of future scenarios in strategic plans for water resources management. Other applications also touch upon the WEAP model as a tool for policy- and decision-making (Huber-Lee et al., 2006; Purkey et al., 2007; Varela-Ortega et al., 2007) and ecosystem services assessment (Vigerstol and Aukema, 2011). Assaf and Saadeh (2008) designed an integrated decision support system based on WEAP modelling and evaluating alternative plans for surface water management in the Upper Litani Basin, Lebanon. Mehta et al. (2011) applied WEAP to analyse river basin management and policy in CABY region, California, where WEAP simulates climate warming's potential impacts on hydrology and hydropower generation. The study shows WEAP model can provide a forecasted condition for the policy making in terms of water transferring and licensing hydropower generation. In the Chinese context, applications of WEAP model in local or basin level water resource management have also been found (Hu et al., 2009; Li and Li, 2010; Li et al., 2015; Ojekunle et al., 2007).

3. Case study

3.1. Study area

Ordos is located in northwest China, covering an area of 87,000 km^2. It is almost completely encircled by the Yellow River to the west, north and east. Ordos is a typical arid area, with 26,200 million m^3 (300 mm) of rainfall (Lu et al., 2002), but 216,880 million m^3 (2500 mm) of evaporation annually. Ordos is positioned at a crucial location between the arid/semi-arid region in western China and the semi-humid region in eastern China. As one of the main physiographic conditions for desertification, the better utilisation of local water resources could be able to slow down the desertification of the surrounding region (Chen and Tang, 2005). The water resources in Ordos come from three sources: surface water, groundwater and transiting water from the Yellow river. The average annual runoff of surface water is 1310 million m^3, of which 260 million m^3 are available for use. By “available,” it means water resource that can be used with existing techniques according to existing policies. The annual recharge of groundwater was found to be 2100 million m^3, of which 810 million m^3 can be re-abstracted. The Yellow River flows over 728 km passing through Ordos, which makes up 14% of its total length. The annual amount of transiting water derived from the Yellow River is 31.6 billion m^3, of which 700 million m^3 are allocated to the Ordos region. According to *The Water Resource Utilisation Plan in Ordos* (Municipal Conservancy Bureau of

Ordos, 2004), the resources available will increase in the future after more reservoirs are built for surface water and wells for groundwater abstraction (Table 1). The annual water consumption in Ordos is approximately 1770 million m^3 in 2007, of which 1466 million m^3 for agriculture, 189 million m^3 for industry, 65 million m^3 for domestic use and 50 million m^3 for public environment.

3.2. SEA case

The studied SEA case is the *SEA for The Leading Industry Development Plan in Ordos (2005–2020)*. The *Leading Industry Development Plan in Ordos (2005–2020)* covers the coal-based industry in the entirety of Ordos. The time horizon of the plan is divided into the short term (2006–2010) and the long term (2010–2015), where this article studies the water demand in the term of 2005–2010. Ordos is rich in coal and natural gas. Its potential reserve of coal makes up 17% of the total amount stored in China. The strategic objective of the plan is to develop Ordos into one of the national bases for energy and chemical industries. The main development activities includes an increase in extraction to 250 million tons of coal (more than 60% of which will be exported), which will contribute to the annual generation of 19.5 million KWH of electricity and 23.4 million tons of coal-based chemical products in 2010. In the long run (2015), the level of coal extraction will remain the same, but there will be a further increase to 25 million KWh of electricity generation and 45.3 million tons of coal-based chemical production. Chemical production covers methanol, dimethyl ether and coal liquefaction, and will make up 10%, 60% and 80% of the total capacity in China respectively.

At the level proposed in these plans, the coal industry in Ordos would consume a significant amount of water. Coal exploration and extraction will release a significant amount of groundwater. Coal-based electricity generation will consume a large amount of water, especially in the cooling process and water is also a crucial factor in coal-based chemical production. A comprehensive picture of the water flows in the Ordos region is sketched out in Fig. 1.

The SEA was conducted in 2007. As one of the first SEAs undertaken in a semi-arid area in China, it investigated the impact of potential activities on the local environment by setting up and analysing scenarios. The SEA study provided a scientific basis for the decision-making process and proposed mitigation measures to secure sustainable development. It was found that water was the most important bottleneck resource in this area, and its utilisation is the core issue among all the tasks that this SEA project should address. Based on the water resource assessment result necessary mitigation should be provided to avoid negative impacts of the planned activities.

3.3. Application of the WEAP

The study area was defined by its geographical extent and is characterised by defining physical elements, including the water demand-supply system and its spatial distribution, time period and priorities (Fig. 2). Ordos is divided into eight municipal regions with very varied water resource distribution systems. Between some of these regions, water can be transferred freely, while in others, there are barriers preventing the transfer of water from one region to another, either because of physical barriers (e.g. distance), or due to municipal priorities. According to their geographical properties, demands are allocated to each of eight sites with links between them and the supplies. The links between demand sites and the treatment facilities were also defined. For each site, the priority of the water resource was established according to the local water resource utilisation plan (Municipal Conservancy Bureau of Ordos, 2004). Taking the ecosystem into consideration, the local water utilisation plan indicated that surface water resources were higher priority than the groundwater. The water resource was analysed based on a budget balance investigation. The water demand was a sum of agriculture demand, domestic demand and industrial demand. The water supply included groundwater, local facilities (e.g. reservoirs), water transfers and reused water by taking the transfer loss into account. WEAP in this case was applied in a temporally simplified way. Instead of taking a monthly time step which is originally set for the model, taking the strategic nature of the plan into account, the study took an annual time step due to three considerations, first, the potential industry activities were planned annually, which in results leads to an annual water demand; second, the fact that each individual industry activity will go through an environmental impact assessment (EIA) process on project level at a later stage, which will deal with demand/supply in a more detailed level (sub-annual/seasonal variation, transfer distance etc.), for which a sub-annual/monthly time step would be possible and make more sense.; and last, as an issue of data availability, the potential future available water resource was also listed in an annual time step.

Water assessment in this study was based on a balance calculation on water demand and water supply. Parameters used for model data input and for modelling output are summarised in Table 2.

3.3.1. Scenario development

Four scenarios were designed in this SEA in order to reflect the impact of *The Leading Industry Development Plan in Ordos* on the local water system. The design of the scenarios was based on the original plan and the relevant policies at the national or local level, such as the *Eleventh Five-Year Plan for National Economic and Social Development in China* (National Development and the Reform Committee, Beijing, China, 2006a), the *National Special Plan for Mine Water Utilisation* (National Development and the Reform Committee, Beijing, China, 2006b) and the *Research on the Sustainable Development of Forestry in Ordos* (Municipal Government and Forestry Bureau of Ordos, 2006). There were assumptions which are common to all four scenarios: the potential available water amount, the scale of planned industry activities, the agriculture land area and, the population in 2010 (which was extrapolated using the population in 2005 and growth rates over the past 10 years as a point of reference). Through the module of population projections for cities and towns, production activity level projections for industry and agriculture, water demand was calculated on a quota basis for different sectors:

Table 1
Available water resources in Ordos (million m^3).

Water resource	Total	Amount currently available (2005)	Potential increase in amount available (2010)	Total potential amount available (2010)
Surface water	1310	260	250	510
Groundwater	2100	810	220	1030
Transit water	31,600	700	0	700
Total available water resources	35,010	1770	470	2240

Date source: "The Water Resource Utilisation Plan in Ordos," Municipal Conservancy Bureau of Ordos (2004).

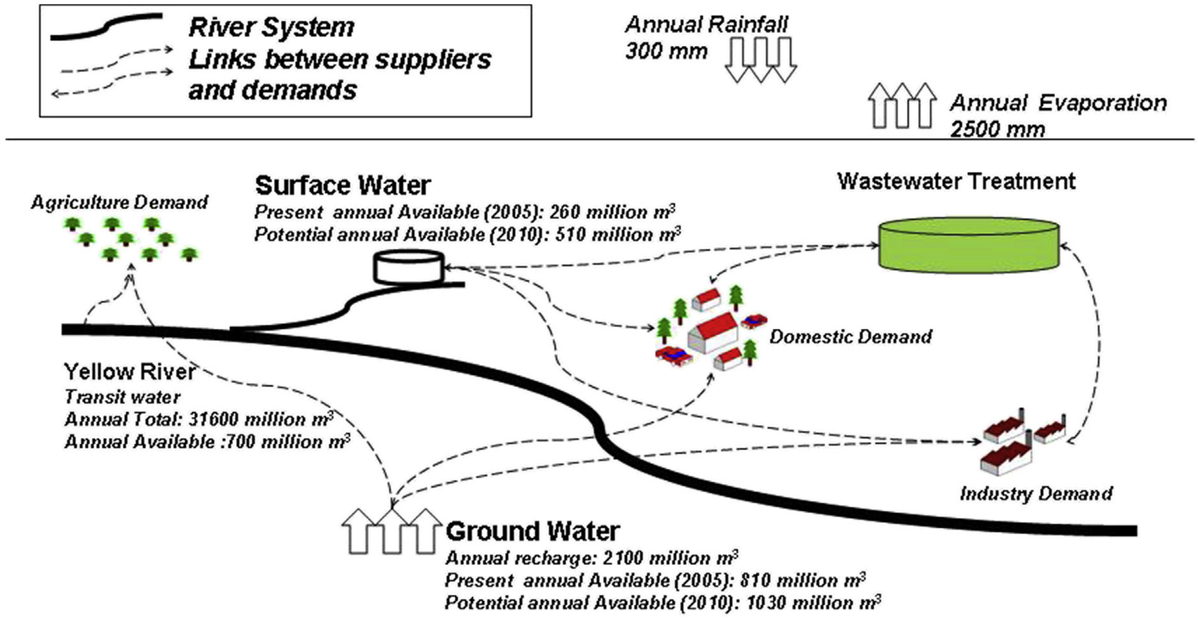

Fig. 1. Water resources and their flow in the Ordos region.

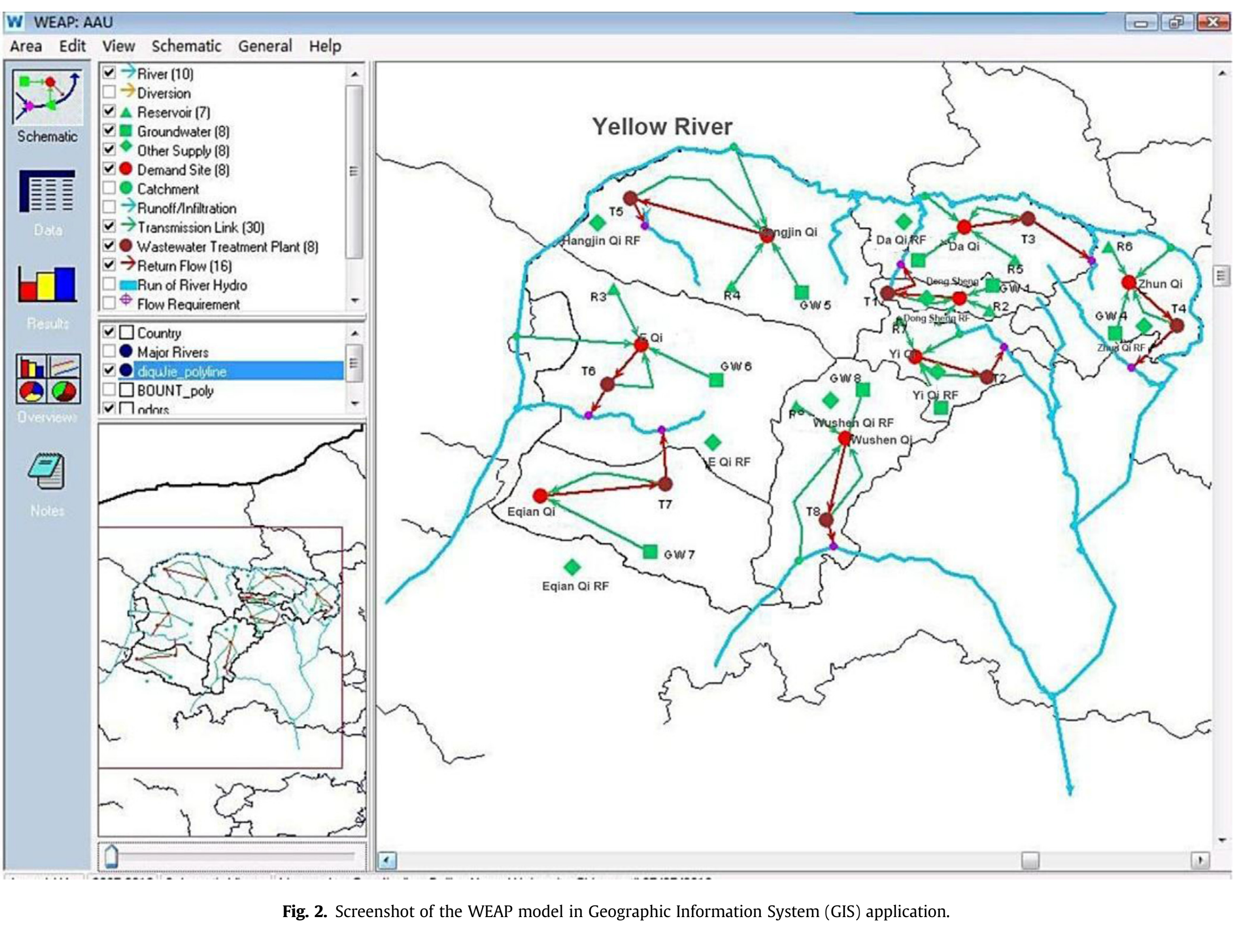

Fig. 2. Screenshot of the WEAP model in Geographic Information System (GIS) application.

Table 2
Key input parameters and output parameters for WEAP in this study.

Area setting Area, population, evaporation, crops, land use patterns, supply preference		
Input		Output
Surface water (current available/future available) Groundwater (current available/future available) Transit water (current available/future available)		Supply requirement: the requirement of each demand site after demand site losses, reuse and savings are taken into account
Domestic quota	Urban area (L/cap·d) Agro- pastoral area (L/cap·d)	Supply delivered: the actual amount of water reaching the demand site after subtracting any transmission losses
Industry quota	Coal extraction (m3/t) Electricity generation (m3/s·GW) Methanol (m3/t) Dimethyl ether (m3/t) Coal liquefaction (m3/t)	
Agriculture	Effective irrigation area (m3/hm2) Irrigation efficiency (%) livestock (L/cap·d)	Unmet
Industrial water reuse rate (%) Domestic water reuse rate (%) Domestic sewage treatment rate (%)		

Annual Industry Demand = Σ *(Total Activity x Industry Water Quota)*

The scenarios differed mainly in their adoption of reuse and treatment measures, which has a significant influence on supply and demand. Increasing water reuse or improving irrigation efficiency will increase supply in the sense that more water will be available to meet the demand. The techniques used for the treatment and reuse of wastewater adopted in the various scenarios will be described in the following section. The different measures tested in the scenarios are described as follows:

- *Industry water quota* - the water demand stipulated in a license (or the use of a certain amount of water per unit of product);
- *Reuse rate of industrial water* - water used for the cooling process in electricity generation, for example, and then used again for the same or other purposes;
- *Mine water reuse* - the percentage of reused groundwater released during the coal extraction process;
- *Domestic sewage treatment rate* - the percentage of domestic sewage being treated;
- *Domestic water reuse rate* - the percentage of treated wastewater, which is being reused for other purposes;
- *Irrigation efficiency* - the fraction of the available amount of water used in evapotranspiration by crops while the remaining part runs off to become groundwater or surface water.

The reuse rate of industrial water is the fraction of wastewater (mainly water used for the cooling process in electricity generation in this case) that is treated and reused for other purposes. The same applies to domestic wastewater. In both cases, the term refers to "external reuse," i.e. neither water saving nor "internal reuse" measures exist in industry or households. Internal water reuse will decrease the water demand of the industry or household, but does not increase the water available on the supply side. External water reuse does not decrease the demand, but increases the supply side. The various measures setting in the four scenarios are shown in Table 3.

Table 3
Different scenarios setting.

Index	Scenario			
	1	2	3	4
Industry water quota	Dependent on the individual product			
Reuse rate of industrial water (%)	90	98	95	98
Mine water reuse (%)	75	90	75	90
Treatment rate of domestic sewage (%)	50	80	85	85
Domestic water reuse rate (%)	None	75	40	75
Irrigation efficiency (%)	35	40	55	55

3.3.1.1. Scenario 1 (planned scenario). This scenario was based on the original plan. It took techniques and measures for saving water and controlling pollution that were already established or planned in 2005. This scenario was considered to be the 0-alternative. The other scenarios took into account extra levels of water saving, pollution control and water reuse. In all of the scenarios, the water consumption quota of the coal industry would be limited using various advanced technical measures. The reuse rate of mine water would be up to 75% in 2010 according to the *National Special Plan for Mine Water Utilisation.* No other measures would be applied for the reuse of industrial wastewater and domestic sewage. In this scenario, the efficiency of the flood irrigation system used by local agriculture was only 35%. Going a step further than Scenario 1, three other scenarios were considered whereby different technologies are applied in order to improve external water reuse or the efficiency of water usage.

3.3.1.2. Scenario 2. In Scenario 2, it was assumed that the reuse of industrial water would increase to 98% compared to the current level of 90%, and that the mine water reuse rate would increase to 90%, in accordance with the *National Coal Industry Development Plan in 2006-2010* (National Development and the Reform Committee, Beijing, China, 2007). According to *Research on the Sustainable Development of Forestry in Ordos* (Municipal Government and Forestry Bureau of Ordos, China, 2006), by adopting low-pressure pipe irrigation, it could make the conservative assumption that irrigation efficiency may increase to 40% compared to 2005. Meanwhile, the treatment rate of domestic sewage would increase as the number of sewage treatment plants increases. In addition, it could assume that the domestic water reuse rate will reach 75% through technical improvements. Based on this scenario, industry demand would be significantly reduced, while the change in agricultural demand would be very small, as efficient water-saving measures were not yet available, as described in the *Research on the Sustainable Development of Forestry in Ordos.*

3.3.1.3. Scenario 3. Scenario 3 emphasised wastewater treatment,

Table 4
Water demand for industries in 2005 and 2010.

Main industry activities	2005		2010	
	Production	Water demand	Production	Water demand
Coal Extraction	150.00 mil t/a	23.00 mil t/a	250.00 mil t/a	37.00 mil t/a
Electricity Generation	4.35 mil KWh	43.00 mil t/a	19.50 mil KWh	178.00 mil t/a
Chemicals	3.16 mil t/a	56.00 mil t/a	23.40 mil t/a	405.00 mil t/a
Total		122.00 mil t/a		620.00 mil t/a

followed by the reuse of treated water. In addition, it was assumed that irrigation efficiency would increase by 20% compared to Scenario 1 and that it would reach 55% due to even more effective sprinkler irrigation (Municipal Government and Forestry Bureau of Ordos, 2006). Generally speaking, this was a relatively high level of irrigation efficiency compared to most other developing countries and regions. In this scenario, the treatment rate of domestic sewage was assumed to be slightly higher than in Scenario 2 and the domestic water reuse rate was assumed to be a mere 40%. Furthermore, a conservative estimate of a 5% increase in the rate of reuse of industrial water was made compared to Scenario 1, in accordance with the relevant policies and plans developed in the *Eleventh Five-Year Plan for National Economic and Social Development in China.*

3.3.1.4. Scenario 4. Scenarios 2 and 3 explored the potential achievement of more environmental objectives than Scenario 1, while Scenario 4 was assumed to combine the advantage of scenario 2 and 3, i.e. to include both higher reuse rate of industry and mining water, and more treatment measures, as well as higher irrigation efficiency (Table 3). A significant amount of water would then be recycled and the local water system could therefore support industrial activity on a larger scale.

3.4. Analysis of the results of modelling

Using the simplified WEAP model, a number of system components were examined for the four scenarios. The effects on the local water system of increased coal mining, chemical industrial activities and electricity generation were analysed. The implementation of each scenario would result in a different impact on the local water resources. The analysis included both existing activities and the proposed water policies. The simulation results of eight demand sites in the four scenarios are shown in Table 5. According to all of the scenarios, the water supply delivered (the actual amount of water reaching the demand sites after subtracting any transmission losses, hereafter referred as "supply") cannot satisfy the supply requirement (the requirement of each demand site after demand site losses, reuse and savings are taken into account, hereafter referred as "demand"). As showed in Table 4, the development plan would lead to an increase in the water demand of 498 million m^3 per year. The amount available in 2010 in Ordos might potentially increase with 470 million m^3 (Table 1), and water shortages, if considering Ordos as one water demand site, did not appear to be as significant as looking into each region separately. Taking into consideration that Ordos consists of eight regions not necessarily connected, it became evident that regions with a lower demand than supply could not necessarily supply their excess water to their neighbours with a shortage, and vice versa (see Table 5). Furthermore, there were very strict constraints regarding the transfer of water from one region to another, which means that surplus water in one region cannot necessarily fill the gap in another.

The impact of implementation of various water policies can be seen in the results of the four scenarios. The more advanced scenarios save a fairly substantial amount of water, and so the water deficit in these regions will diminish as a result of the implemented measures. In Scenario 1, the water deficit of 376.9 million m^3 for the entire Ordos is, by implementation of the water policies stipulated in Scenarios 2, 3 and 4, reduced to 46.5 million m^3 a year. The scenarios could, in other words, not deliver enough water, even with extensive use of wastewater treatment and water reuse. This means that the water system cannot support the scale of industry planned if no measures other than those included in Scenario 4 are taken. The original plan should therefore be adjusted.

3.5. Optimisation with a new scenario 5

Water resource assessment within the SEA provides a scientific basis from which to assess and mitigate the environmental impact of plans on nature. In this case study, it was found that for all four investigated scenarios using effective reuse and treatment measures, there would still be an unmet demand for water. In this SEA, it therefore had to look for yet another "optimal" and more appropriate scenario. Taking into account that the most optimal reuse and recycling measures have been included in the designed scenarios, optimisation had to be based on another balance

Table 5
Water balance based on different scenarios in 2010.

Site	Scenario 1 (million m^3)			Scenario 2 (million m^3)			Scenario 3 (million m^3)			Scenario 4 (million m^3)		
	Supply delivered[a]	Supply requirement [b]	Unmet	Supply delivered	Supply requirement	Unmet	Supply delivered	Supply requirement	Unmet	Supply delivered	Supply requirement	Unmet
Da Qi	485.2	602.2	117.0	485.2	554.0	68.8	440.2	440.2	0.0	405.0	405.0	0.0
Dong Sheng	62.0	86.1	24.1	67.6	68.8	1.2	57.3	72.1	14.8	57.6	57.6	0.0
E Qi	109.9	109.9	0.0	82.4	82.4	0.0	100.9	100.9	0.0	75.6	75.6	0.0
Eqian Qi	153.4	153.4	0.0	141.1	141.1	0.0	131.4	131.4	0.0	120.9	120.9	0.0
Hangjin Qi	247.9	247.9	0.0	245.4	245.4	0.0	188.9	188.9	0.0	187.0	187.0	0.0
Wushen Qi	260.1	260.1	0.0	239.3	239.3	0.0	166.1	166.1	0.0	152.8	152.8	0.0
Yi Qi	148.5	206.0	57.5	141.6	144.2	2.6	154.2	194.0	39.8	135.8	135.8	0.0
Zhun Qi	151.8	330.1	178.3	151.8	214.6	62.8	151.8	305.1	153.3	151.8	198.3	46.5
Total	**1618.8**	**1995.7**	**376.9**	**1554.5**	**1689.9**	**135.4**	**1390.8**	**1598.7**	**207.9**	**1286.6**	**1333.2**	**46.5**

[a] Supply delivered: the actual amount of water reaching the demand site after subtracting any transmission losses.
[b] Supply requirement: the requirement of each demand site after demand site losses, reuse and savings are taken into account.

between water management and the reduction of production in the proposed plan for Ordos. This new scenario, based on Scenario 4, further included the reduction of production capacity compared to the original proposal (cf. Table 6). Considering that coal-based chemical production creates the largest demand for water, after the regional economic advantages analysis, it was suggested that the scale of coal liquefaction in 2010 be decreased from 5 million tons per year to 2 million tons per year, and that the production of dimethyl ether in 2010 be decreased from 4.7 million tons per year to 2.9 million tons per year (which would lead to a decrease in the total coal-based chemical production from 23.4 million tons per year to 18.6 million tons per year). The suggested coal-based chemical production reduces the water consumption by 78 million m^3 per year, which would significantly reduce the pressure on local water resources in areas plagued by drought.

4. Discussion

In SEA, water resource assessment is performed as one of many contributions to a broader assessment of the plan in question. In this case study, it first became clear that water issues should be at the top of the agenda. On one hand, this case demonstrates some positive light on how an applied model like WEAP could be integrated in SEA. On the other hand, the SEA also encountered several barriers, which gave the following lessons about how to handle various difficult aspects of performing an SEA, which have been experienced in this study.

In this SEA case, WEAP model acts as a useful tool with its GIS-based simulation to provide rapid assessment results in two aspects. Temporally, WEAP model gives SEA a good flexibility on the temporal level in simulating future impact, although it originally is based on a monthly time step and its later update allows calculation based on a weekly or even a daily time step (SEI, 2011) It provides SEA practitioners possibility in simplifying a complex model to an appropriate level that fits the strategic nature of the plan. In this SEA case, the accounting has been simplified to an annual time step due to the fact that industry activities were planned annually and the fact that each individual industry activity would go through an environmental impact assessment (EIA) process on project level at a later stage, which could deal with demand/supply in a more detailed level (sub-annual/seasonal variation, transfer distance etc.), for which a sub-annual/monthly time step would make more sense. From this point of view, the level of information provided by an annual time scale is valuable. Spatially, the model also shows that it has particular advantage in dealing with large geographic scale with distributed water demand sites. Especially in this case, a rather large study area of 87,000 km^2 poses difficulty in taking geographical concerns into consideration. Instead of giving an overall water balance accounting, the model provides function of water balance accounting with spatial distribution – according to the planned industry activities' layout, which grants SEA practitioners a very useful tool in dealing with different conditions among geographic sites, which in turn also ensures SEA giving mitigations depending on geographical conditions. An additional practical benefit is that WEAP model supports GIS-based result illustration, which efficiently provides rapid assessment results displayed on different geographical levels for decision-making purposes.

And for the SEA process, when looking into forecasts for the future, it is useful to work with properly-defined scenarios in SEA in order to draw reliable comparisons. At the same time, scenarios define the feasible policy instruments and thus set the framework within which mitigation demands can be imposed on water users. However this case we experienced difficulty in designing a feasible mitigation scenario to mitigate the impact of the proposed activities on the local water system: the designed scenarios have taken into account the strictest water usage policies and the most advanced existing techniques available, while, even under the most positive scenario, the local water system cannot support such large-scale development activities in the near future, which indicates that the proposed plan has to be adjusted. This result leads to a further discussion on the uncertainties that to be addressed in the scenarios of SEA: scenarios in SEA rarely regard the proposed activities as an uncertainty, due to which, no enough attention has been paid in assessing this uncertainty as a variable in different scenarios.

5. Conclusion

This study describes the first attempt to apply an integrated water resource assessment model to an SEA case in China using a simplified version of the WEAP model. The WEAP model measured the impact of the implementation of a proposed plan on the local water resource system. In order to describe this impact, four scenarios were analysed, which differed mainly with regard to the utility measures (irrigation efficiency, wastewater treatment and the reuse of water etc.) that were adopted. This model made it easy to simulate and compare the results of different water utilisation scenarios. Based on the simulation of the results, an optimal solution should be found among the assessed scenarios. However, it was not easy to outline scenarios from the start that covered realistic mixtures of mitigation measures, as the scenarios were not radical enough. As none of the scenarios assessed could sustain the planned activities relating to the expansion of coal mining, electricity generation and coal-based chemical production, a new scenario based on the reduction of industrial activities was proposed.

With this first experience in China, the WEAP model appeared to be a useful tool for the rapid assessment of water utilisation as part of the conclusion of the SEA. As PPP normally provide only a relatively brief design instead of a detailed description, it is important to keep the data and information used during the SEA process on a reasonably aggregated level. This definitely constitutes one of the advantages of the WEAP model, as it can deliver information on an aggregated level. WEAP can temporally evaluate water resource management based on an annual time step, which fits most SEA cases, while there is still possibility to take the water resource assessment at a monthly, weekly even daily time step due to the flexible data aggregation. Its capacity of dealing with distributed demand sites in large spatial scale, which has been tested in this

Table 6
Optimisation of the original plan.

Area of the coal industry	The proposed plan		The optimised plan (Scenario 5)		Water demand reduction
	Production	Water demand	Production	Water demand	
Coal production	250 mil t/a	37 mil m^3	250 mil t/a	37 mil m^3	0
Electricity generation	19.5 mil KWh	178 mil m^3	19.5 mil KWh	178 mil m^3	0
Coal chemical production	23.4 mil t/a	405 mil m^3	18.6 mil t/a	327 mil m^3	78 mil m^3
Total		620 mil m^3		542 mil m^3	78 mil m^3

*t/a: tons per year.

case, is another advantage to be applied in SEA. Furthermore, the user-friendly interface provides a platform for the communication of local water management. It is relatively efficient to change one of the variables in order to test the results of different scenarios, which can significantly improve SEA's efficiency.

Lessons were also learned in this case study. On one hand, due to the data availability and spatial scale, this SEA case paid more attention on social-economic water resource system that influenced significantly by human social activities than on water resource system relating to the ecosystem. Uncertainty in model operation due to inefficient consideration of ecosystem water demand is identified as a short-come of this case study. So between time and financial costs during the SEA process, and a broad scope for investigation, there is a trade-off for the SEA practitioners in practice. Based on this case's experience, further research paying more attention on ecosystem water demand, long-term climate scenarios and even results comparison with similar models could be a valuable attempt for a broader application of WEAP as an efficient and effective tool in the SEA process. On the other hand, inspired by the discussion on the failure in taking proposed activities as a variable in different scenarios in this SEA case study, future study on the scope of scenarios could be valuable to further deepen the SEA research.

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