Groundwater Management and Exploration Package: Scenario Analysis

GMEP-Project

DRAFT

Groundwater Management and Exploration Package: Scenario Analysis

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Preface

This report presents an approach to scenario analysis of groundwater resources in Northern China with particular reference to GRACE satellite monitoring and the WEAP planning tool.

This study is undertaken in the context of the GMEP project (Groundwater Management and Exploration Package). GMEP is financially supported by the Dutch Government through its program Partners for Water.

More information on the GMEP project can be found at the project website:
http://www.futurewater.nl/gmep

Consortium:

Dutch project partners:
- FutureWater (Wageningen)
- Delft University of Technology (Delft)
- Water Board Rivierenland (Tiel)

Chinese project partners:
- Shiyang River Basin Management Bureau (Wuwei)
- Hydrology and Water Resources Investigation Bureau (Wuwei)
- Tsinghua University (Beijing)

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1 Introduction

Groundwater depletion in Northern China, has reached catastrophic levels. Across the northern half of the country, groundwater over-pumping amounts to some 30 billion cubic meters a year. Water resources analysis rely more and more on advanced tools including data assimilation, simulation modeling and remote sensing (Van Loon et al., 2007). Remote sensing has been used extensively to detect land cover and related parameters, where the extension to monitor evaporation is in the transition phase from research to operational application (Immerzeel et al., 2006). Simulation models are commonly used in water resources planning and operation, where understanding processes and evaluating scenarios are the main objectives (Droogers et al., 2008). These tools are increasingly applied in an integrated manner, where remotely sensed observations can be used to calibrate hydrological models (Immerzeel, 2008).

The two main tools included in the Groundwater Management and Exploration Package (GMEP) are GRACE and WEAP. GRACE is a twin-satellite monitoring changes in the earth's gravity field. These changes have a direct correlation to groundwater storage fluctuations. GRACE information will form the base in GMEP to assess current and past groundwater trends. WEAP (Water Evaluation And Planning system) is a user-friendly package able to link supplies and demands in water resources and will be used to evaluate future alternatives in sustainable groundwater management.

The GMEP (Groundwater Management and Exploration Package) project will demonstrate that advanced observations and planning tools can assist decision makers. In this report a demonstration of the ability of the WEAP management tool to support scenario analysis will be given for the Yellow River Basin.

2.1 WEAP model

The original WEAP model as presented in an earlier report (Hermans et al., 2008) was used as reference to evaluate a set of scenarios (Figure 1). The original model was setup for the years 1998 to 2000. However, no GRACE soil water observations were available for that period and it was therefore decided to run the model for 2006.

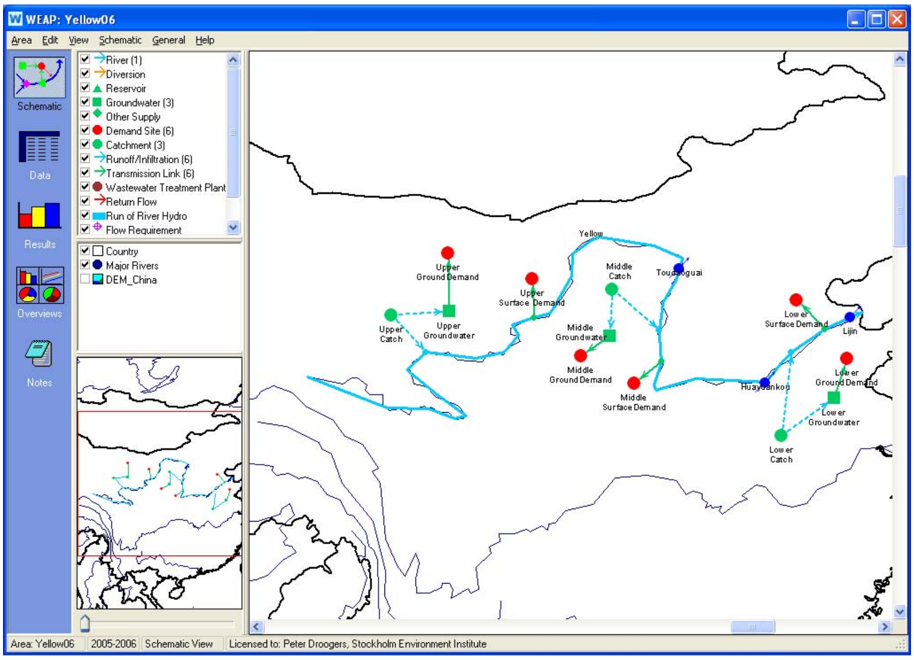


Figure 1. WEAP model of Yellow River Basin.

2.2 Precipitation data

The advanced TRMM precipitation data (Kumerrow et al., 1998) were used as these provide a unique and consistent set of information covering large areas at a relatively detailed spatial resolution (Figure 2 top left).

TRMM (Tropical Rainfall Measuring Mission) provides precipitation estimates at fine spatial scales using a calibration based sequential scheme and data from multiple satellites as well as gauge analysis. In this study the 3B43 product is used (Hufmann et al., 2007). This is a monthly product with a spatial resolution of 0.25^{o} (~ 25 x 25 km). The original processing occurs at a time interval of three hours. Firstly, a number of passive microwave sensors aboard TRMM and other satellites are converted to a precipitation estimate. Secondly, an infrared (IR) estimate is generated using the calibrated microwave estimate. Thirdly, the microwave and IR estimates are combined to provide the best estimate at each grid box at each three hour period. The final step in generating 3B43 is the inclusion of rain gauge data. It is highly advantageous to include rain gauge data in combination data sets. All 3-hourly combined microwave and IR estimates are then summed over a calendar month to create a monthly multi-satellite product. Using the gridded precipitation gauge based product of the Global Precipitation Climatological Centre (Rudolf, 1993) a bias correction is performed in similar way as described in Hufmann et al. (1997).

2.3 GRACE observation

Groundwater monitoring was performed using GRACE satellite monitoring. Details regarding GRACE (Gravity Recovery And Climate Experiment) can be found in the first GMEP report (Hermans et al., 2008) and will not be repeated here.

Information of groundwater monitored by GRACE is always expressed to a certain reference level. It is therefore that this information can be presented in various ways. The most commonly used reference levels are shown in (Figure 2):

- Deviation from a long term average (2002-2007) for all months
    - e.g. a value of -10 mm in June 2007 cm means that the total water storage in that month is 10 mm lower compared to 72 months (6 years x 12 months).
- Deviation from a long term monthly average
    - e.g. a value of -5 mm in September 2006 cm means that the total water storage in that month is 5 mm lower compared to 6 other months (6 years June).
- Deviation from the previous month
    - e.g. a value of +20 mm in February 2008 means that total water storage in Feb-2008 is 20 mm higher compared to Jan-2008.

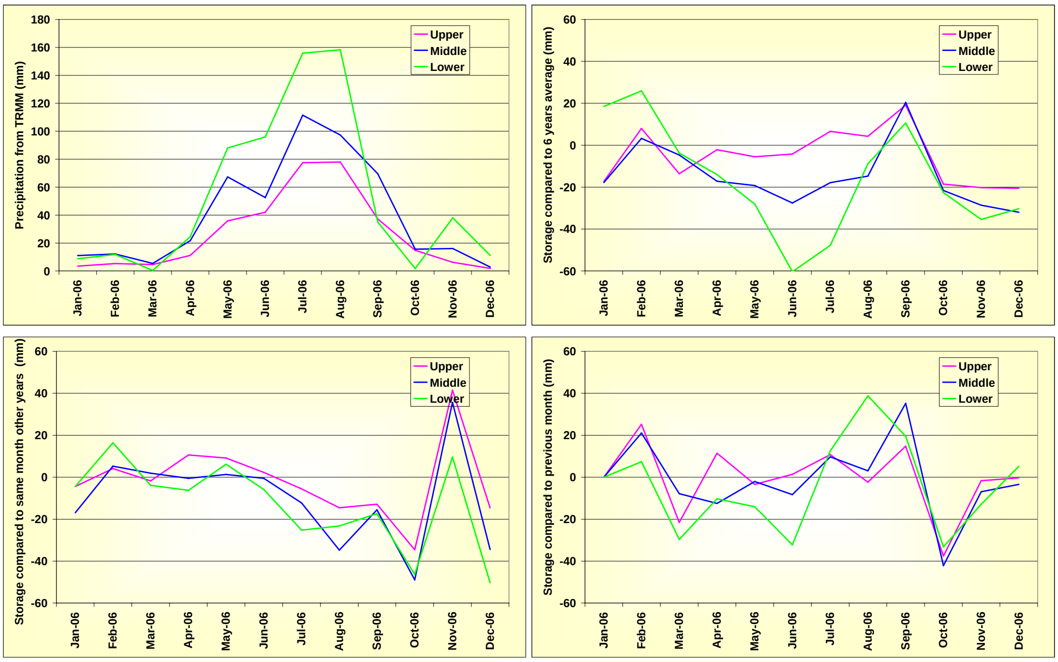


Figure 2. TRMM precipitation (top left) and total groundwater derived from GRACE presented using three reference levels (see text).

2.4 Verification

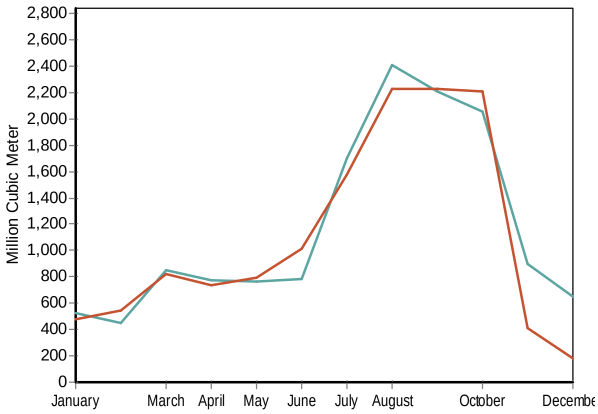
Observations of GRACE as presented in the previous section are compared to WEAP model results. As mentioned, GRACE detects only changes in total soil moisture and no absolute groundwater table depths can be detected. WEAP can provide absolute groundwater storage values, but since data on aquifer characteristics are lacking, it was decided to present the WEAP output also as changes to a mean.

Comparison between WEAP and GRACE for the three reaches for 2006 indicates that the fit is reasonable and similar trends are found (Figure 4). It should be emphasized that the WEAP model applied is a very course one and that hardly any other calibration or validation has been applied.

Moreover, the model as developed will be used for scenario analysis only, and not to project actual values. It has been proven before (Droogers et al., 2008) that relative model accuracy is always higher than absolute accuracy, so that for scenario analysis a fully calibrated and validated model is not crucial.

In summary, we can conclude that the developed model can be used for scenario analysis as:

- the WEAP model is able to simulate observed groundwater levels by GRACE to a reasonable level
- as demonstrated earlier WEAP (Hermans et al., 2008) is able to simulate observed flows (Figure 3)
- relative model accuracy is higher than absolute accuracy.



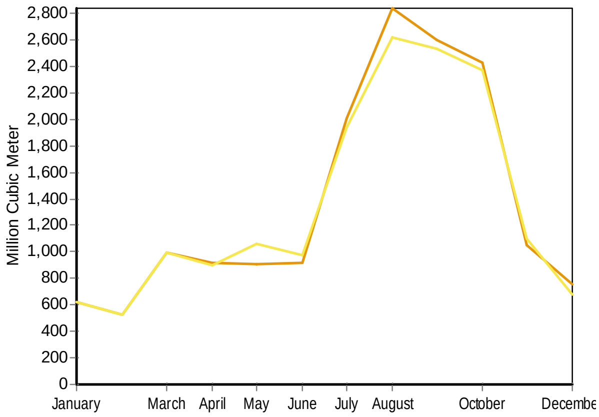


Figure 3. Observed (blue, orange) and simulated (red, yellow) streamflow for Upper Reach (left) and Middle Reach (right). Monthly averages over the period 1998-2000.

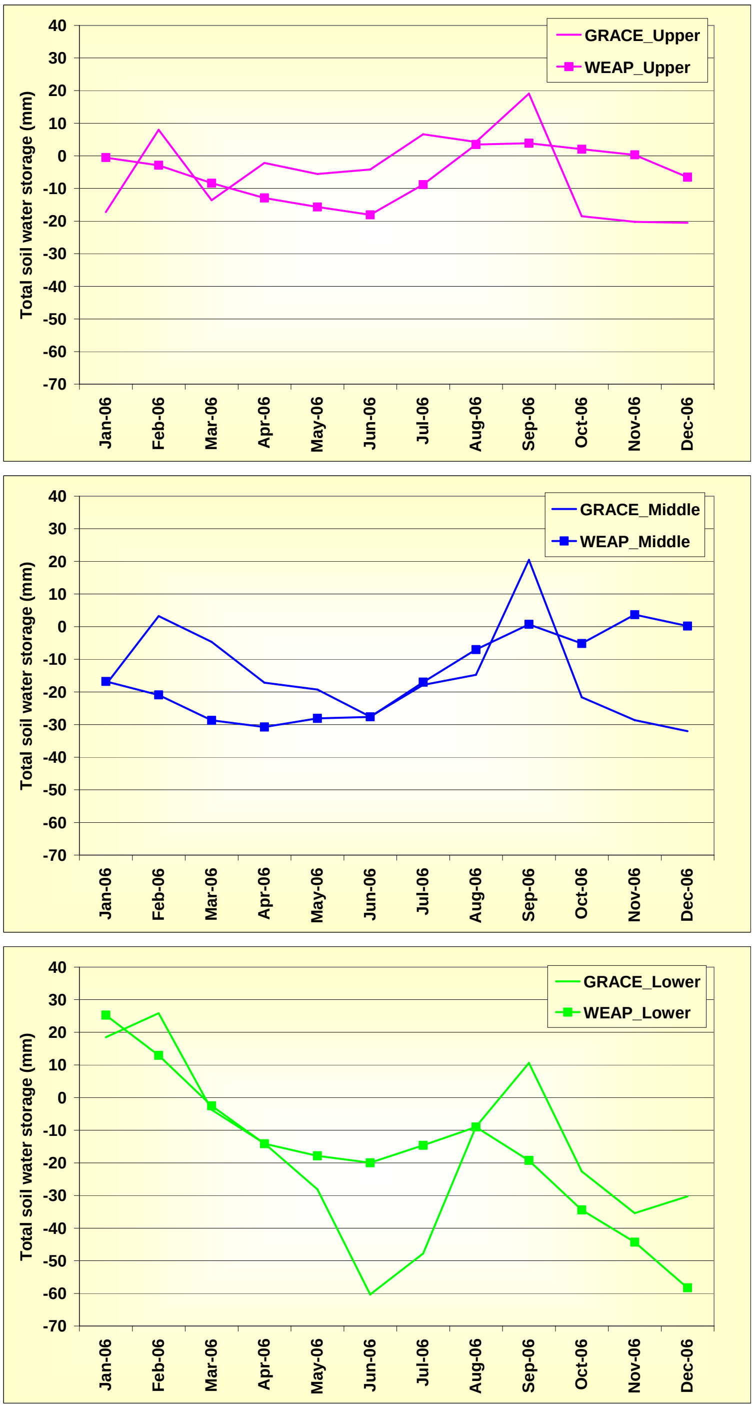


Figure 4. WEAP groundwater levels compared to GRACE observations. Results reflect total soil water storage (GRACE) and groundwater only (WEAP), relative to the long term average (6 years) for the three reaches.

3 Scenario Development

3.1 General

Based on various publications and expert knowledge the following set of scenarios has been defined that are evaluated using WEAP:

A: Reduced groundwater extractions
B: Interbasin transfer
C: Climate change

These three scenarios are all compared to one baseline year (2006). This year was selected as it represents the most recent year with moderate dry conditions and sufficient data. Some background on these scenarios and the way these scenarios are implemented in WEAP is explained in the following sections.

3.2 Scenario A: Reduced groundwater extractions

Changing policies might make it possible to decrease groundwater extraction in the Yellow River basin. This requires however legislation and more particular to enforce these rules. It would be however important to assess the impact of such a measure before implementing. The base line WEAP model as described previously has been altered to reflect these changes.

For the three reaches the following changes has been made to mimic this scenario:

- Annual Water Use Rate
    - UpperGroundDemand: from 2 BCM to 1.5
    - MiddleGroundDemand: from 8 BCM to 6
    - LowerGroundDemand: from 3 BCM to 1.5

At the same time, restrictions on groundwater extraction will force user to extract water from surface water resources, if available. This is reflected in WEAP by increasing the surface water demand for the three reaches:

- Annual Water Use Rate
    - UpperSurfaceDemand: from 15 BCM to 15.5
    - MiddleSurfaceDemand: from 11 BCM to 13
    - LowerSurfaceDemand: from 11 BCM to 12.5

3.3 Scenario B: Interbasin transfer

Inter-basin transfer is considered as an option to overcome water shortages problems in the Yellow River Basin. The Yangtze River is the longest one in China with plenty of water resources with a mean annual runoff of 960 billion m^3 and 760 billion m^3 in extreme dry year. Since about 94% of the river water flows into the East Sea annually, it is possible to transfer water from the Yangtze River Basin to the northern area. This so-called South-to-North Water Transfer Project started already in 1950s, with the following general layout of the project: three water transfer sub-projects, i.e. Eastern Route Scheme (ERS), Middle Route Scheme (MRS) and Western Route Scheme (WRS). With the natural advantages of the Yellow River crossing the north China from the west to the east the national adjustment and allocation of water resources between the South-to-North Water Transfer Project and the Yellow River will be realized. The annual total water transferred will be after completion of the project about 45 billion m^3. For the current scenario analysis we consider that an 10 BCM will become available at the head end of the Yellow River.

In order to evaluate the impact of this South-North transfer in WEAP the following adjustment to the base line model has been made. First of all 10 BCM / y will be added to the Yellow River:

- River > Yellow > Headflow > 317 CMS (= 10 BCM / yr)

At the same time it is expected that extractions from the groundwater will be reduced and much more water will be extracted from surface water:

- Annual Water Use Rate
    - UpperGroundDemand: from 2 BCM to 1
    - MiddleGroundDemand: from 8 BCM to 4
    - LowerGroundDemand: from 3 BCM to 1
    - UpperSurfaceDemand: from 15 BCM to 18
    - MiddleSurfaceDemand: from 11 BCM to 17
    - LowerSurfaceDemand: from 11 BCM to 15

3.4 Scenario C: Climate Change

It is expected that climate change will have a substantial impact on water resources. The IPCC in its latest fourth Assessment Report published climate change projections that forecast an increase of precipitation for Yellow Basin with on average about 10% on an annual base. At the same time temperatures are expected to increase by about 3 to 4 degrees, increasing water requirements and evapotranspiration substantially .

The expected combined impact will be that groundwater recharge will be somewhat lower and at the same time that surface water demand will increase. This has been implemented in WEAP by the following assumptions:

- Precipitation: increased by 10%
    - Reference evapotranspiration: increased by 20%
- Annual Water Use Rate
    - UpperSurfaceDemand: from 15 BCM to 20
    - MiddleSurfaceDemand: from 11 BCM to 17
    - LowerSurfaceDemand: from 11 BCM to 15

3.5 Implementation of scenarios

Within WEAP scenarios can be implemented easily. Figure 6 shows how the three scenarios as identified can be implemented in WEAP. Figure 7 shows for one example that only data that differs from the reference have to be altered.

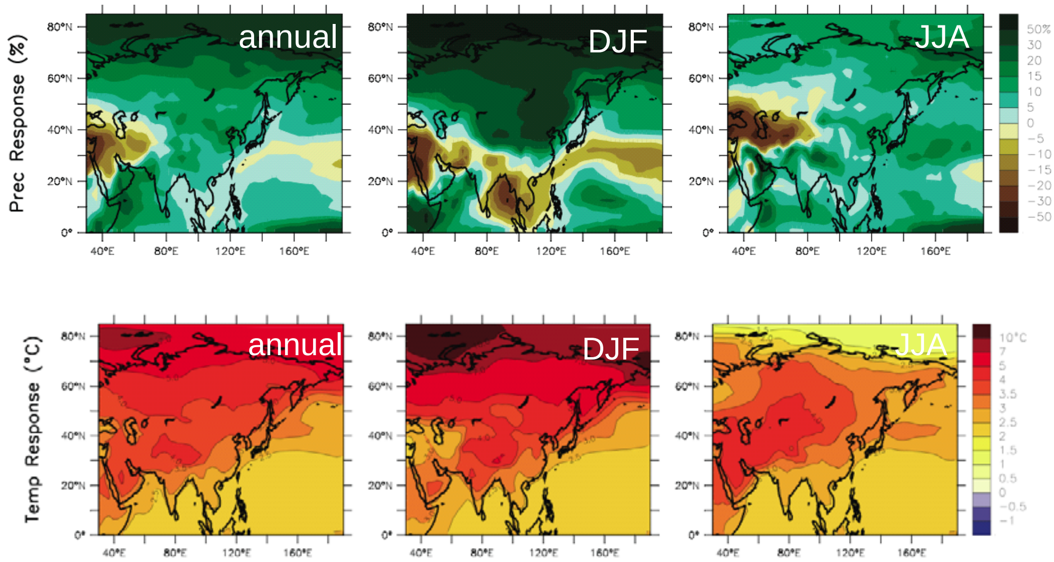


Figure 5. Changes in temperature from the MMD-A1B simulations between 1980 to 1999 and 2080 to 2099 (IPCC, 2007).

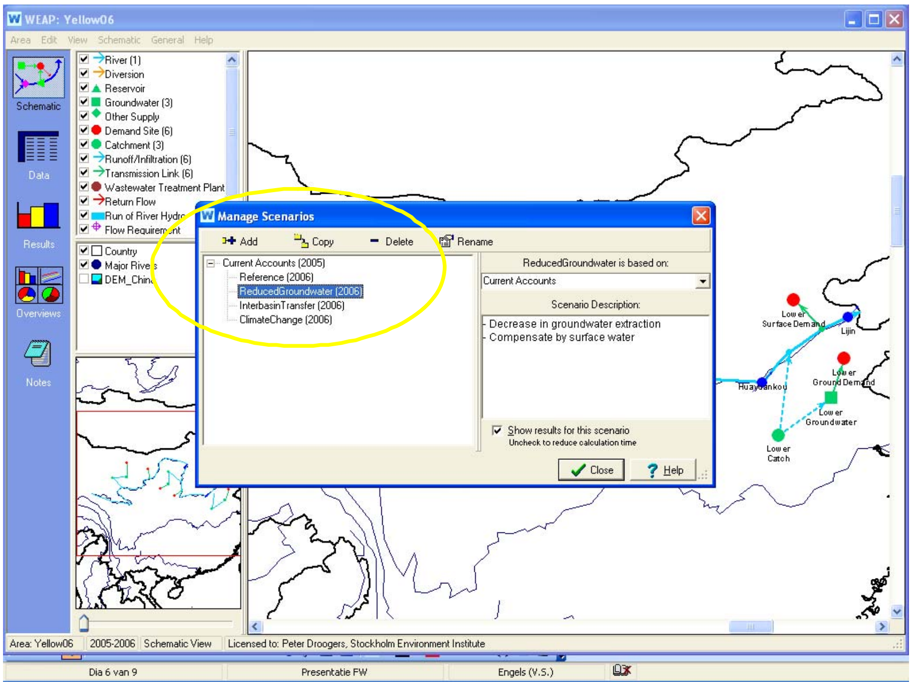


Figure 6. Development of three scenarios in WEAP.

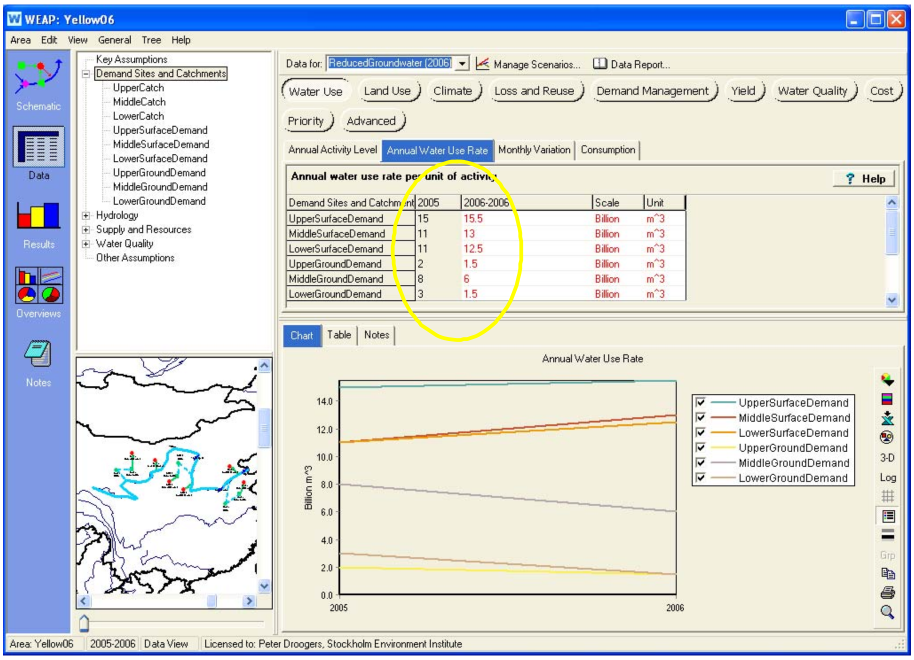


Figure 7. Example of implementation of a scenario in WEAP. Here changes in demand for the reduced groundwater scenario are shown.

4 Scenario Results

4.1 Overall impact

Results of the scenario analysis should be expressed by indicators. For this specific study the following key indicators have been defined (all in BCM[1]):

- Total demand
- Unmet demand
- Outlfow to Bo Hai sea
- Changes in groundwater

A summary of the scenario analysis, using these key indicators, can be seen in Table 1. Some of the most interesting points of this table are:

- Total demand is increasing for the inter-basin transfer. Since on would expect a return on investments this will lead to this higher demand.
- Highest increase in total demand is caused by climate change.
- Unmet demand (water shortage) is going to increase under each scenario.
- Only under the inter-basin transfer scenario outflow to Bo Hai sea will increase.
- The reduced groundwater extraction and the inter-basin transfer scenarios will lead to a recovery of groundwater levels.

Figure 8 provides the same information as Table 1 but now in graphical form. Table 2 shows the differences, in %, compared to the base line.

Impact of the scenarios is obviously not constant in time. Figure 9 shows the changes in groundwater storage for all aquifers in Yellow River Basin for the year 2006 on a monthly base.

Table 1. Summary of the scenario analysis. All values in BCM.

		Base Line	RedGr	Interbasin	CC
Total Demand		50.0	50.0	56.0	65.0
	Groundwater	13.0	9.0	6.0	13.0
	Surface Water	37.0	41.0	50.0	52.0
Unmet Demand		3.9	6.8	9.5	16.5
	Groundwater	0.0	0.0	0.0	0.0
	Surface Water	3.9	6.8	9.5	16.5
Outflow Bo Hai		8.2	7.1	10.9	7.5
Groundwater Change		-0.2	3.4	5.3	-0.8
	Upper	-0.1	0.3	0.8	0.1
	Middle	1.2	3.0	4.1	0.4
	Lower	-1.4	0.0	0.5	-1.2

[1] BCM is billion cubic meter, 10^9 m^3

Table 2. Summary of the scenario analysis compared to the base line. All values in %.

	RedGr	Interbasin	CC
Total Demand	0	12	30
Groundwater	-31	-54	0
Surface Water	11	35	41
Unmet Demand	74	144	323
Groundwater	0	0	0
Surface Water	74	144	323
Outflow Bo Hai	-13	33	-9
Groundwater Change	-1,800	-2,750	300
Upper	-416	-831	-156
Middle	150	242	-67
Lower	-100	-133	-10

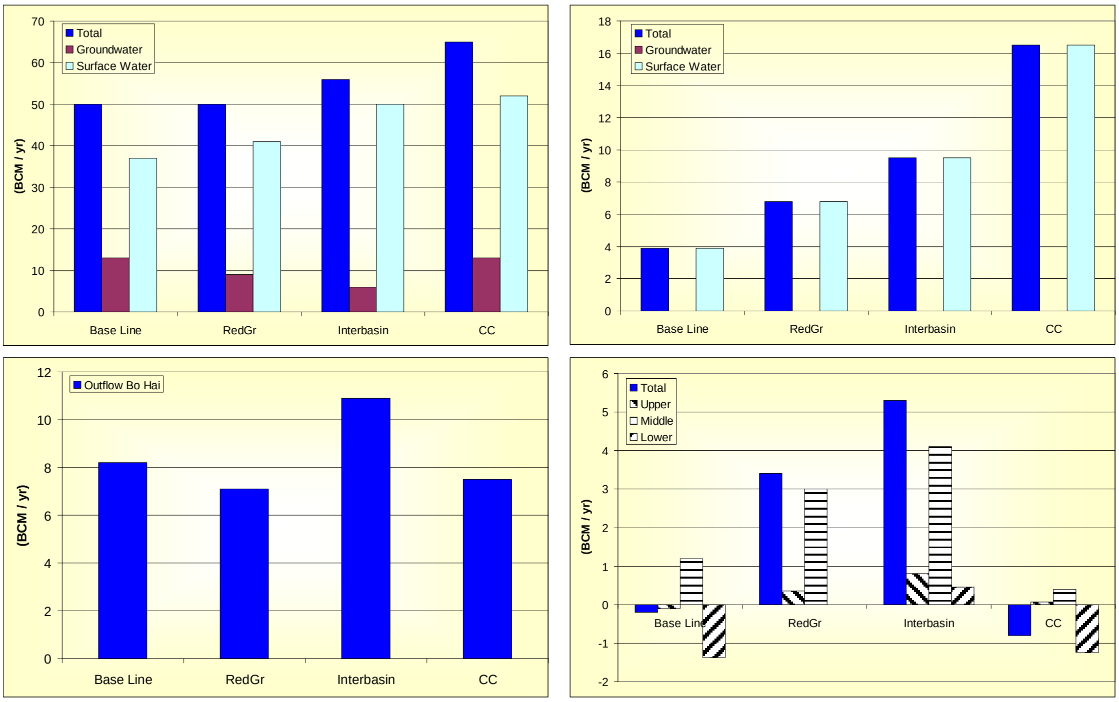


Figure 8. Summary of scenario results (similar to Table 1).

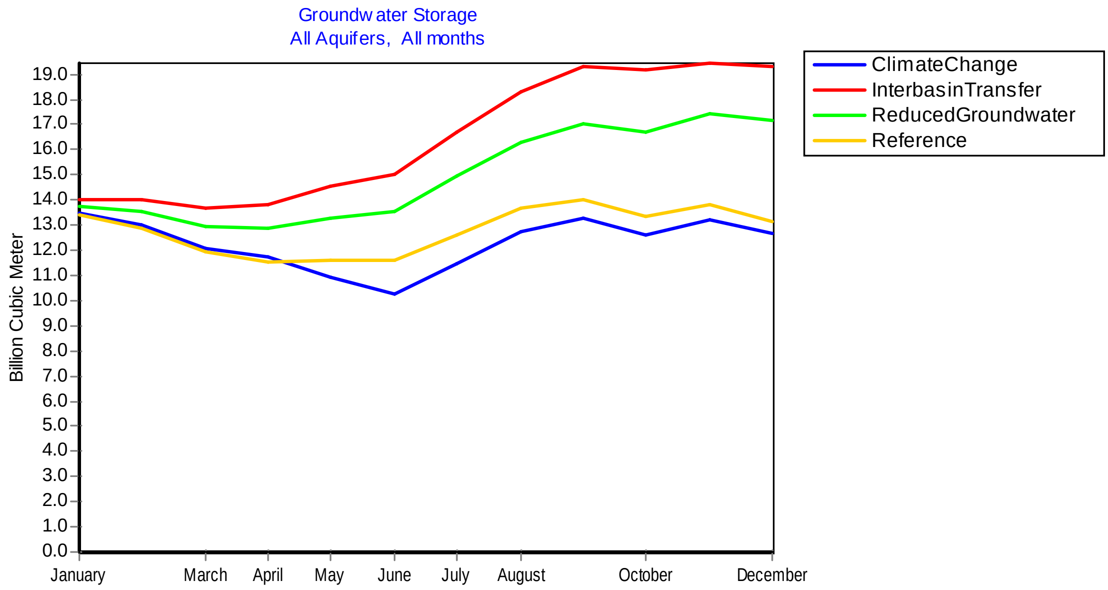


Figure 9. Monthly groundwater storage for the base line and the three scenarios.

4.2 Google Maps application

In order to present spatial differences a Google Maps tool was developed. This tool, the Google Maps Groundwater Tool (GMGT) enables to present data in a spatial distributed way. A typical example of this tool is shown Figure 10, where the TRMM data for July 2003 is presented.

GMGT was also used to present the results of the scenario analysis. Two typical screenshots of GMGT can be seen in Figure 11. The Figure shows for April and November what the impact will be off climate change on groundwater resources. Due to the increase in temperature evaporative demand will go up and groundwater levels in April will be lower compared to the base line. However, climate change projections in Northern China show an increase in precipitation, so groundwater levels will go up in the wet season. However, the combined effect is still that, on an annual average, groundwater tables will be lower compared to the basin line (Table 1).

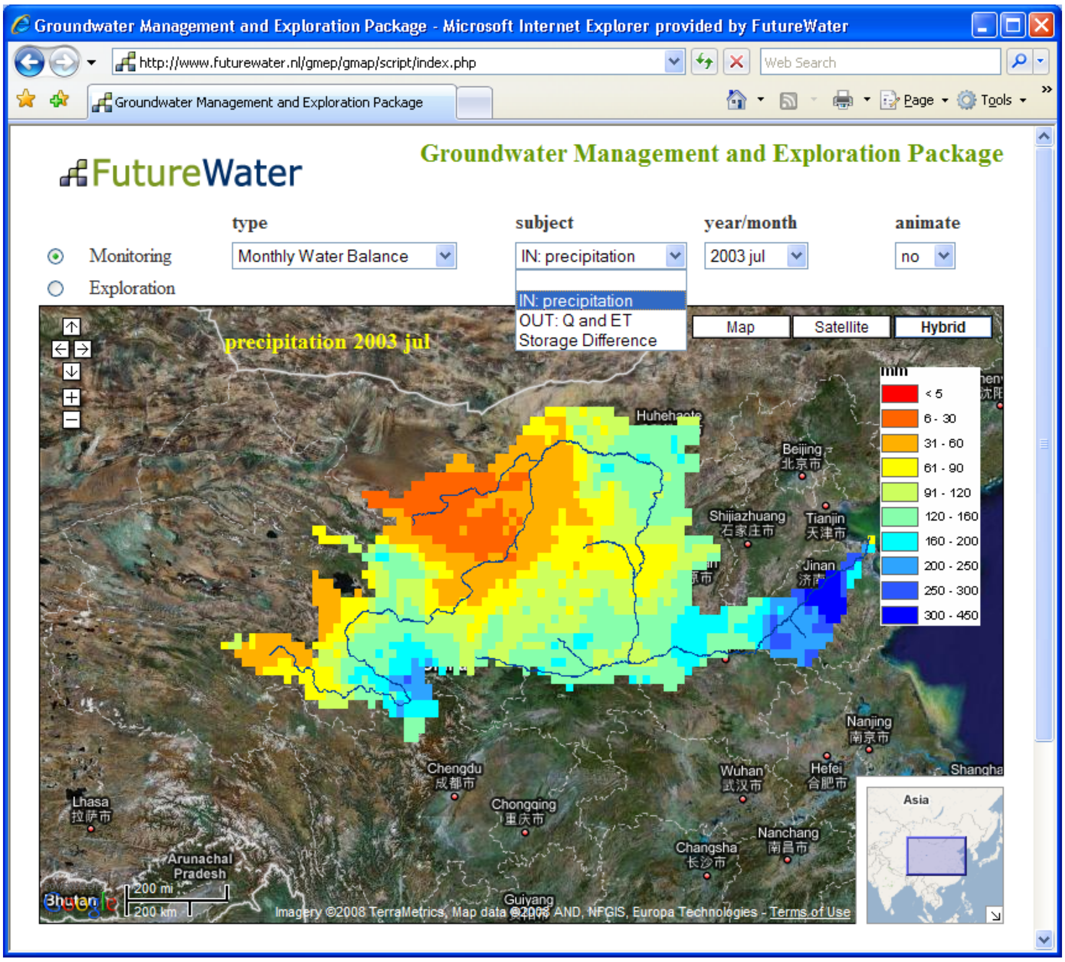
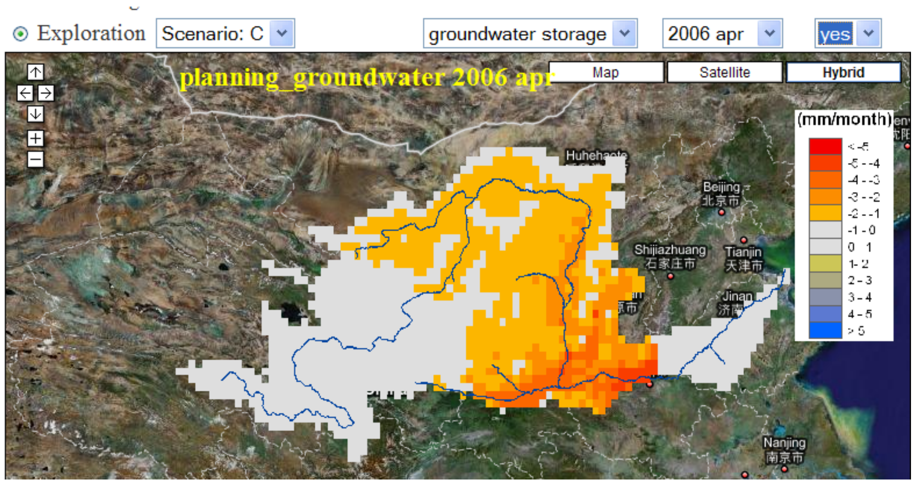


Figure 10. Precipitation in July 2003 as presented in the Google Maps Tool as developed under the GMEP project. (source: http://www.futurewater.nl/gmep/)



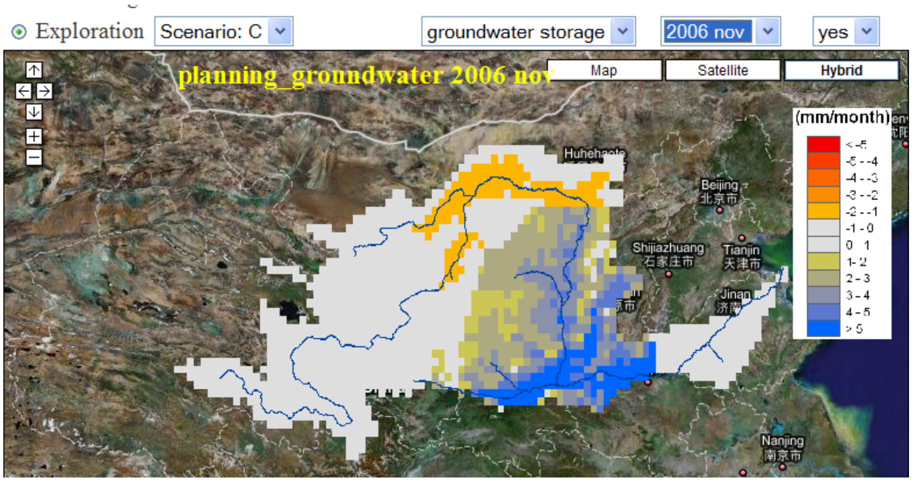


Figure 11. Example of spatial distribution on groundwater changes under a climate change scenario. (source: http://www.futurewater.nl/gmep/)

5 Conclusions and Recommendations

This report should be considered as a demonstration of what scenario analysis can offer to support decision making, rather than a final evaluation of options to improve groundwater management in Yellow River Basin. The study indicates that decision makers can be supported by a combined use of satellite information for monitoring and evaluation the past, with a modelling approach to evaluate options for the future, linked to a spatial presentation tool in Google Maps.

In summary the following conclusions and recommendations can be made:

- Satellite observation of groundwater changes using GRACE is feasible.
- The WEAP model is able to reflect the impact of changes in management on groundwater.
- The Google Maps Groundwater Tool (GMGT) is an attractive way to present monitoring and modelling information.
- Additional data would improve the accuracy of the models and therefore the reliability of the model.
- Scenario analysis would benefit from further involvement of stakeholders to ensure realistic scenarios.

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