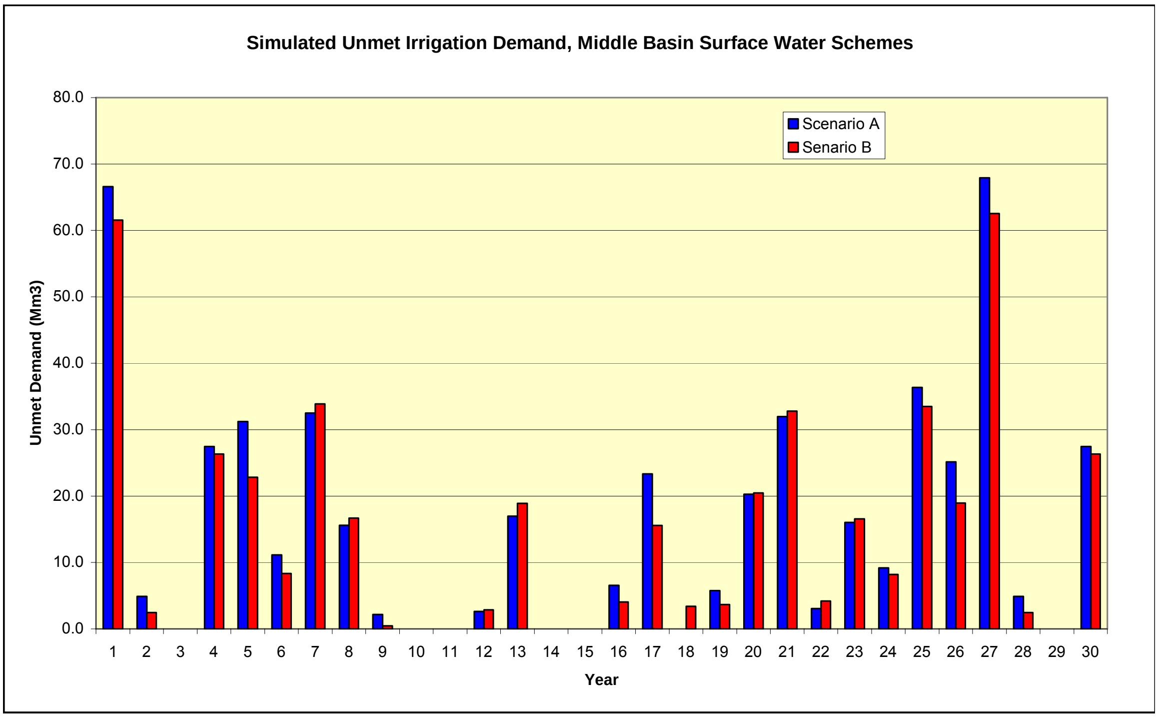
2. IWRM

China – UK, WRDMAP
Integrated Water Resources Management Document Series

Advisory Note 2.3: Water Resources Scenario Development and Scenario Modelling

May 2010



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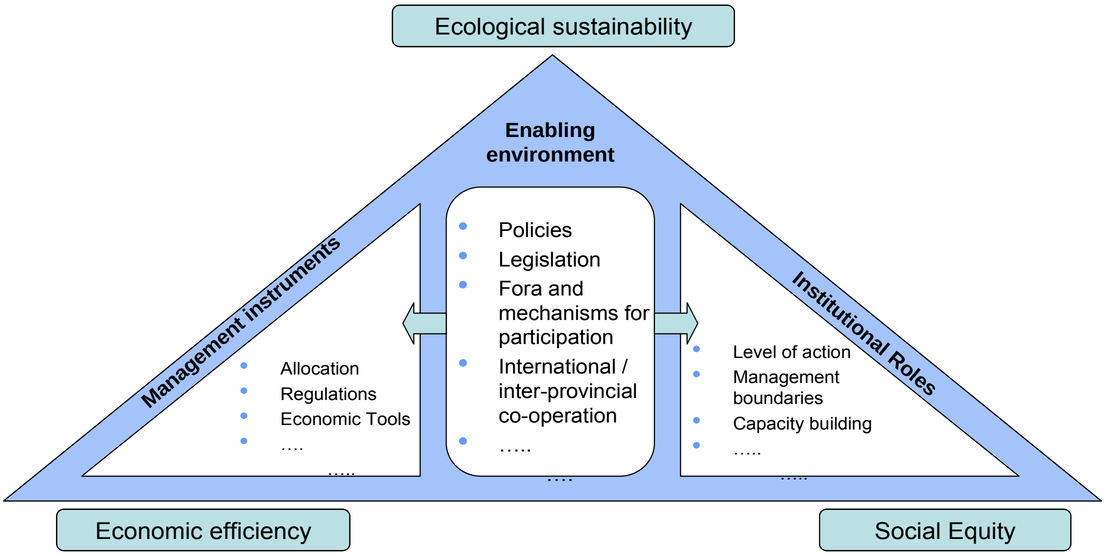
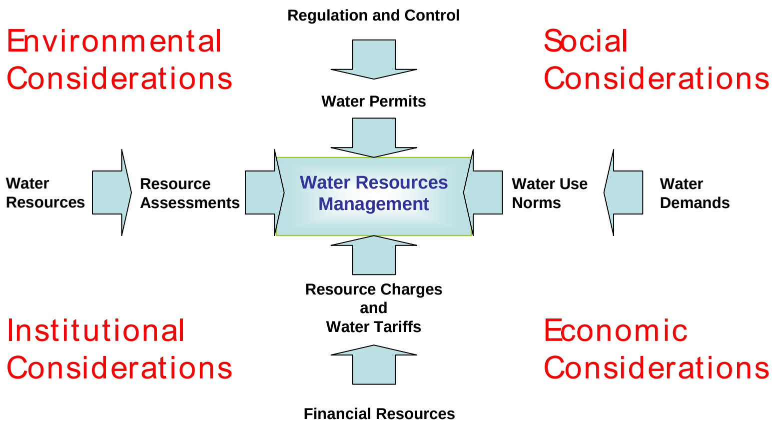
Integrated Water Resources Management (IWRM)

(Basics after Global Water Partnership)



Driving Elements of Integrated Water Resources Management



(Second figure after WRDMAP)

Summary: In most water resources planning problems there will be several alternative means by which a certain set of objectives can be met. Any particular combination of water demand projection, water resource availability assessment, and resource development plan would be termed a **scenario**. Normal practice in water resources planning is to consider and evaluate a range of scenarios that will eventually constitute a plan or the basis of a plan.

Generally a system simulation model is used to evaluate alternative scenarios because it can provide a variety of results on the performance of individual resource system components, supply reliability, crop yields, net income, operating costs, net present values etc. These can then be used to help planners and stakeholders in decision making. However, simulation modelling can only do so much. There is a requirement for the pre-processing and post-processing of information and this is also very important.

This Note provides advice on developing and using scenarios for planning purposes:

- Introduction
- Scenario analysis for IWRM planning
- Specifying scenarios
- Scenario evaluation and modelling
- Examples of presentation of results

This document is one of a series covering topics on sustainable water resources planning and water allocation. Of particular relevance is the companion Advisory Note 2.1 'Developing an IWRM Plan'.

The Ministry of Water Resources have supported the Water Resources Demand Management Assistance Project (WRDMAP) to develop this series to support WRD/WAB at provincial, municipal and county levels in their efforts to achieve sustainable water use.

1 Introduction

There is never only one solution to a problem nor a single series of events that will happen in the future. Further, no analysis is exact nor any assumption perfect. For these reasons scenario analysis is a required process of water resources development and management.

In most water resources planning problems there will be several alternative means by which a certain set of objectives can be met. It will also generally be the case that a certain amount of uncertainty surrounds projected water demands, and future water resource availability. It is therefore necessary to develop plans in the knowledge that adaptation and adjustment will almost certainly be required as the future unfolds. Alternative plans should therefore be assessed against alternative projections of future demand and resource availability. Some plans will be more adaptable than others, and will of course exhibit better performance against chosen sets of criteria than others. Evaluation criteria might include economics, sustainability, and environmental impact.

Any particular combination of water demand projection, water resource availability assessment, and resource development plan would be termed a scenario. Normal practice in water resources planning is to consider and evaluate a range of scenarios.

An analysis of development and (management) change scenarios is important in terms of both integrating or reviewing different plans, policies and interventions such as their impact on the water resource regime, economic and social development and environmental impact can be assessed and subsequently discussed. The analysis of different scenarios provides an invaluable method of discussing the content of the analysed scenarios with stakeholders. Decision makers also need to be fully aware of the broad implications of the various scenarios formulated. Apart from various plans and development options scenario analysis is often related to 'what if' analyses. A vital aspect of scenario analysis is the thorough and transparent documentation of the data used and assumptions made. Elements of these will undoubtedly be an aspect of any sensitivity analysis undertaken.

2 Scenario Analysis for IWRM planning

2.1 General

Scenarios are developed from an understanding of the particular river basin, the issues and problems, and the management alternatives or possibilities for managing these problems. They are developed and selected on the basis of their contribution to meeting water resources development and management planning objectives. Both short and long term impacts of scenarios should be analysed as some management options may be practical in the short-term but lead to long term problems (eg. increased water consumption). A process of integrated water resources management (IWRM) is often seen as the most effective way of achieving goals of sustainable water resources development and use.

It should be emphasised that where simulation modelling is concerned:

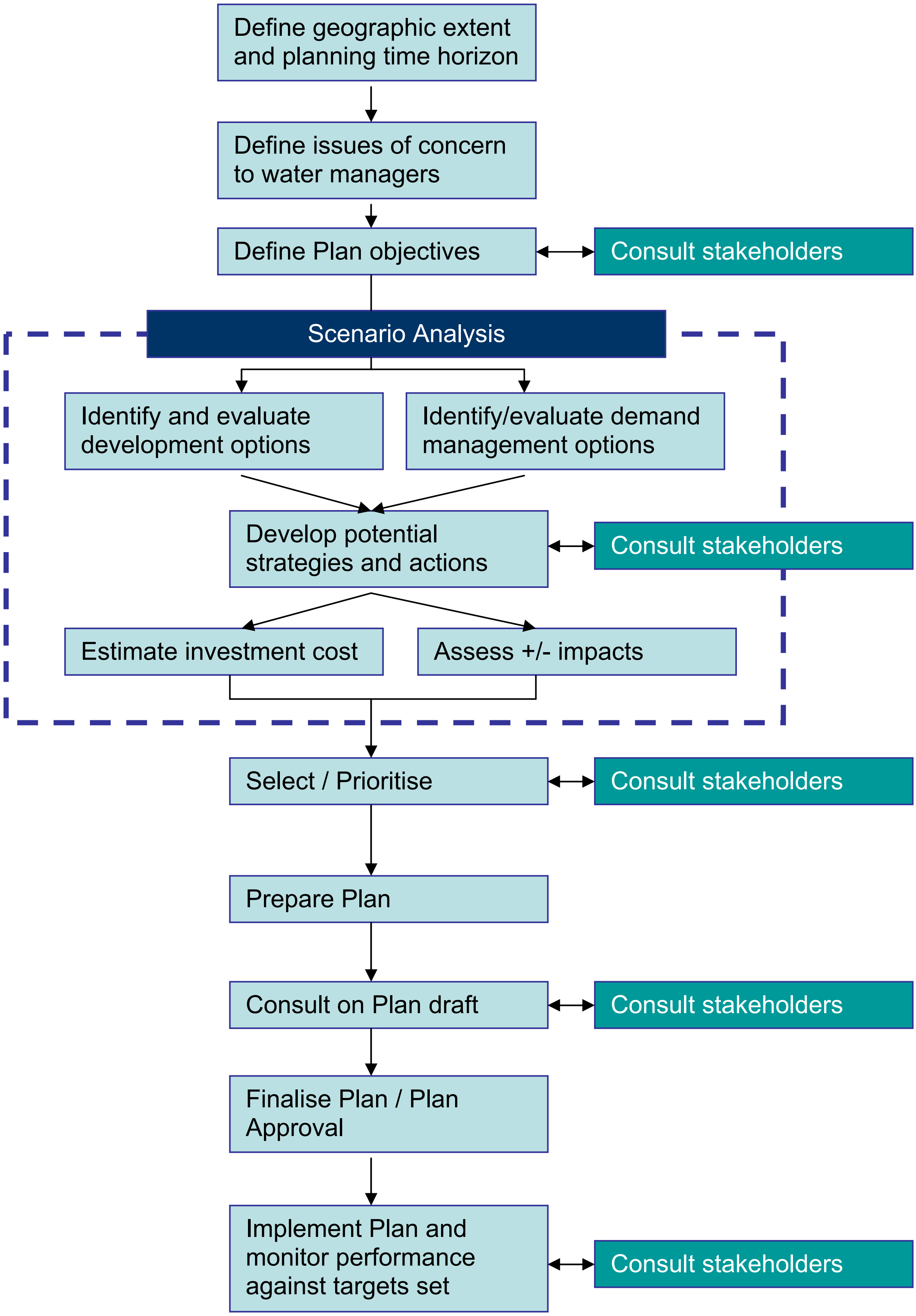
1. Results should always be considered as indicative and should generally be used as a comparator between alternative scenarios rather than an absolute answer.

2. Translating a scenario (of water use) from a 'real situation' to an input data series for a model production run will entail assumptions and simplifications that need to be taken into account when analysis the model results.

Figure 1 shows the importance of scenario analysis in the sequence of steps involved in IWRM planning. It also emphasises the role of stakeholder participation in the IWRM process.

There are related documents in this series that deal with the development of IWRM plans, stakeholder participation in the planning process, and the choice of suitable models to aid the planning team in analysing scenarios. Refer to the bibliography at the end of this Advisory Note for details.

Figure 1: The IWRM planning process



2.2 Understanding water management issues

Prior to any future scenario analysis it is useful to review historic plans:

- Main features
- Predictions
- Achievements (physical)
- Actual implementation sequence versus the planned schedule (and reasons for discrepancies if any)
- Impact of the plan
- Issues associated with the plan
- General lessons learnt during plan implementation (and regarding the planning process)

Past and current plans for different sectors and for different purposes should be included in this review process – the selection criterion being relevance to water resource management and the objectives for the new planning initiative for which scenarios will be analysed.

2.3 Criteria for decision making

Water resource planning involves the selection and ranking of the most appropriate scenarios for the future management of available water resources. The evaluation, selection, and prioritisation of scenarios and actions should reflect a society's choices. Therefore developing an IWRM Plan means articulating the core values on which to base decisions, determining what outcomes are sought and defining what trade-offs those will entail.

Effective prioritisation should not be based solely on one or two key criteria like water resource implications (effects on water demands and use and availability) and economic performance (benefit/cost ratios). Social, institutional, management, environmental and financial criteria will be other important factors influencing the choice, especially for the non-technical stakeholders involved.

Whatever approach is used for the selection and ranking process, the selection criteria should be developed and agreed with key stakeholders before the scenario analysis is carried out. The initial scenarios are often predefined by the content of development plans and the targets of various sector agencies as well as known popular opinion in relation, for example to a water service delivery and/or an environmental condition.

Multi-criterion decision analysis (MCDA) provides an effective structure and mechanism for refining and making transparent this selection process (see bibliography).

2.4 Generic scenarios

Scenarios need to be:

- Robust
- Plausible, and
- Compellingly differentiated

Scenarios for evaluation can be categorised as baseline conditions, possible human interventions, or risks to water resources use in the river basin. Baseline conditions are used in comparisons against proposed actions to assess the benefits of the proposals.

Baseline conditions

There are two baseline conditions.

The first of these is the **current situation**. One important aspect of scenario planning is the need for a sound knowledge of what the true status of water use is in the current situation. This water use situation must been linked to a good estimate / assessment of the baseline infrastructural and development level (socio-economic etc) conditions that are related to this water use situation. What are the per capita use characteristics, what are the industrial production details that relate to current water use levels, what are the current losses in the distribution systems, what crops are being irrigated and what are the estimated losses in the irrigation systems? All this needs to be carefully documented otherwise scenario development and planning cannot realistically be undertaken.

The current baseline situation is also needed so that the impacts of taking 'no action' can be fully understood and included in stakeholder consultations as well as in awareness-raising (see Box 1).

Box 1 "No Action" or "Business as usual"

Such scenarios allow water resources managers and stakeholders to review the future impacts of continuing water usage at current rates of development – to assume that recent trends in water use continue unchanged up to the planning horizon (say 30-50 years ahead).

In most cases this will be worse than the situation right now. Such scenarios send a strong message saying we cannot continue to ignore the problem, and can be used to convince affected stakeholders of the necessity for change.

The second baseline condition is based on the 'natural' river flow and aquifer conditions and is particularly useful in assessing environmental impacts of human interventions. In almost all cases rivers and aquifers are no longer in this condition so it is necessary to synthesise 'natural' river flow sequences by removing the influence of human interventions (the process is called *naturalising* or *un-impairing* the flow series). Certain key characteristics of the natural flow are assumed to be essential to maintaining the aquatic environment – see Section 3.2.

Human interventions

This includes a wide range of possible human interventions such as reservoir construction, increased or decreased irrigation, groundwater development, canal lining, improved irrigation practices, changed cropping patterns, inter-basin transfers, catchment re-vegetation, and changed reservoir operating conditions. The opportunity should be taken to look at a wide range of 'what-if' possibilities including those not currently planned or which seem initially impractical.

It has been very common for governments throughout the world to focus on **structural measures** (ie built infrastructure interventions). However, in developed countries over the last 20-30 years, structural measures have not been favoured, or are not seen as the only solution. It has been learned from experience that such measures can be expensive, may not always be justified in economic terms, and can, if not managed carefully, lead to unintended longer term consequences often involving environmental degradation.

Non structural measures are now preferred by governments, particularly where structural facilities have already been built and are often not being operated with due concern for the environment or sustainability factors. These non-structural measures involve policy and management approaches and are a much more economically efficient and usually more effective form of intervention. Examples of these measures for water resource management include demand management approaches such as water permitting, water pricing, and water saving approaches within the built infrastructure (pipe networks, canals, etc).

Risks to water resources use

Scenarios that are investigated should also include important risks to water resources management in the river basin. This could include drought, periods of heavy precipitation, climate change, or the failure of management or physical systems (e.g. failure of water transfers, accidental releases of hazardous chemicals or waste, reservoir failure, polluted drainage from mining operations, etc).

2.5 Use of models

Once selected, analysis of the impacts of the various scenarios can be made in many ways. However, using computer simulation models of the hydrological behaviour of a river basin has many advantages, providing that the data and information used is of good quality and sufficiently robust and that the uncertainties of both the input and output are understood.

It is important to understand that models **only support the thought processes that lead to decisions**; they aid understanding of the issues affecting the resource system, including understanding of the impacts of uncertainty. Natural resources data and information is always far from certain and projections are based on numerous assumptions. Managers and experts have to make judgments and decisions based on their wider understanding of the situation, and models can only help in this.

2.6 Analysis and evaluation of scenarios

Figure 2 shows how the Plan actions are developed by an iterative process of testing alternative scenarios.

Scenario analysis must include analysis of the range of economic, environmental and social impacts of the scenarios. These analyses need to emphasise the near term impacts of the scenarios but it is also important that the longer term impacts are evaluated as these can be serious and may be undervalued by economic analysis. There should be a phased introduction of interventions and consideration of changes within the management planning process, and the near-term, mid-term and long-term.

It is important to review and analyse the sector plans of sectoral agencies and to ensure that these and their potential impacts on the water environment are clearly understood.

Cross sectoral impacts should be explicitly considered as these are often not well considered in planning by sector-based agencies (hence the international emphasis on adopting IWRM practices). On the basis of the results of the analysis (economic, social, environmental), decision makers will decide whether impacts or conflicts between sectors (including the environment as a sector) are acceptable, or whether the scenario needs to be modified to an extent that more acceptable impacts are obtained.

The results of these analyses and deliberations should form the foundation for stakeholder communication and consultation. A wider public consultation should also be undertaken.

It is necessary to identify what will be the "measurement points" (specific geographical locations) and "performance indicators" (statistics or qualitative descriptions) by which to compare scenarios. These will be specific to the basin under study. Table 1 lists a number of typical indicators.

3 Specifying Scenarios

3.1 General

The characteristics of the scenarios need to be developed and recorded in specific terms for two reasons:

1. So that possible scenarios and their characteristics can be included in the evaluations made.

2. So that there is a record of the scenarios analysed for future reference and so that decision makers know the basis of the evaluation results.

The preparation of scenarios must involve stakeholders to ensure that the scenarios tested in a particular planning round cover all matters of concern.

Step by step scenario building

It is important to define the time horizons to be considered i.e. in this round of planning what is to be the definition of 'mid-term' or 'long term'?

The hydrological data series used in the water resources modelling tools for each scenario will normally be the same as used for the baseline runs. This is because even though the scenarios deal with changes in resource use, there may also be scenarios that involve an actual change to the hydrological data series e.g. investigation of potential climate change impacts on available resources.

A key issue is the hydrological (runoff/river flow) record used in the analysis. Average flows may give an indication of impacts but generally it is the frequency and magnitude of extremes or extended periods of drought or flooding that is of more importance. For this reason, it is best to use as many years of hydrological record as possible to drive scenario analysis. In practice, lack of data may mean that alternative approaches need to be used.

The changes, if any, in infrastructure that are to be included (eg additional reservoir capacity, different operating rules for reservoirs, withdrawal of selected abstraction permits, assumed new boreholes etc) in a scenario need to be clearly defined and enumerated.

All assumptions made in the build up of the hydrological (resources) data and water requirements for different users (demands) for any scenario must be recorded in a standard format.

Figure 2: Scenario analysis for developing an IWRM plan

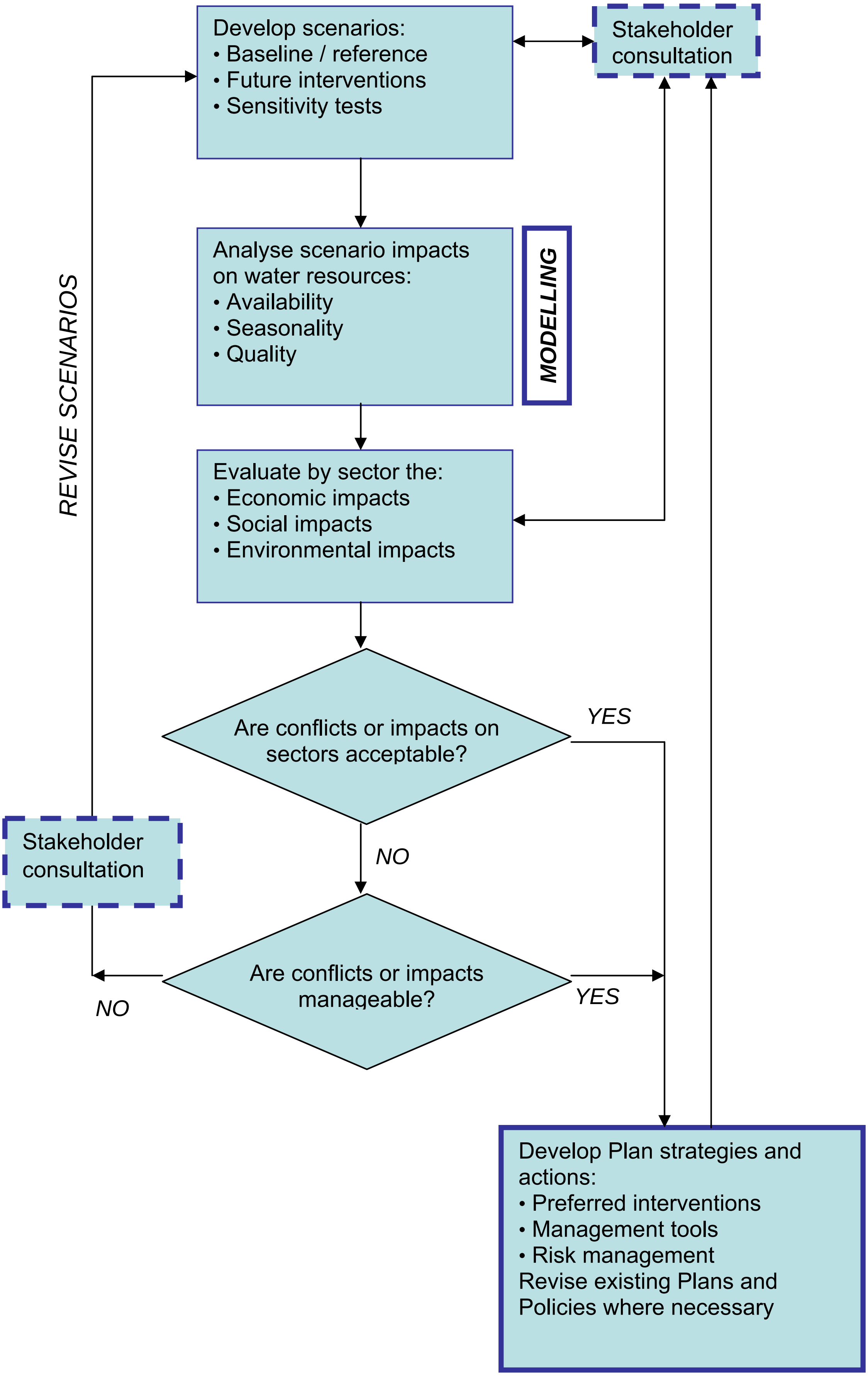


Table 1 Typical performance indicators

Parameter	Attribute(s)
Flow regime at key location(s)	Annual flow statistics Flow duration characteristics
Groundwater level at key location(s)	Depth to water table Sustainable levels
Deficits in supply at key location(s)	Frequency and magnitude
Value of production	Basin-wide net value of production
Water quality of water body	Quality classification /status Concentration of selected chemical(s) in relation to target
Environmental flow in river reach	Flow duration curve
Preserve target wetland area	Water table regime Flood inundation frequency
Use for groundwater	Change in number of operating wells
Socio-economic indicators	Net value of production per ha Cost of water Security of supply Population served by piped water supply Hydropower energy production per annum

3.2 Demand forecasting

A water resources plan may be required to address a number of often competing water demands. These might include potable water demand, industrial water demand, agricultural water demand, maintenance of environmental flows, navigation, and hydropower production. The manner in which these demands can be forecast is briefly discussed in the following sections (and Thematic Paper 1.8 and Advisory Note 1.8/1 'Water Demand Forecasting').

In developing the scenario it is important to identify the source of water to meet the demand as surface water (reservoir, lake, river, transfer) or groundwater, and to identify the location of abstraction.

Forecasting potable water demands

Potable water demands are generally built up from forecasts of population growth and forecasts of changes in per-capita water consumption, and forecasts of changes in distribution system leakage rates and other water saving/efficiency improvements.

Population growth forecasts are generally linked to national forecasts, and to demographic changes that are in turn linked to socio-economic development plans. There are thus various factors that will influence actual population growth at any locality, and a range of projections is normally investigated, with upper and lower bound estimates being made. There will be little difference between forecasts in the short term, but the longer the forecasting horizon, the wider will be the gap between upper and lower bound projections. In establishing population growth forecasts it is necessary to liaise with local planning authorities.

Changes in per-capita water consumption are related to socio-economic development, to the design of domestic appliances, and to social attitudes to water use and water saving. With socio-economic development there is generally a shift to more water using household appliances, and this can result in increased water consumption. Improvements in the efficiency of these appliances have helped to limit the rate of per-capita demand growth in many countries. Changes in per-capita water consumption will depend on the base from which they are starting. Where there exists low per-capita consumption, higher rates of growth might be expected than where there are higher rates of consumption in the first place. Regional and district variations are to be expected in per-capita consumption rates. Water pricing can also influence per capita consumption – knowledge of price-demand elasticities is required.

With the rapid increase in both urbanisation and the quality of dwellings in the urban areas, per capita demands in cities are bound to change with time. For provincial cities, it may be of use to consider the changes that have taken place in Beijing and Tianjin over the last 30 years (Box 2). This can provide a basis for the development of per capita water supply growth scenarios. Water usage per capita is also directly related to household income and this factor can be used to make within-city and between city estimates more realistic (this is related to both ability to pay and the number of appliances and size of the dwelling occupied).

Box 2 Growth in per capita water demand – Beijing and Tianjin compared

As the nation's capital, Beijing has a much higher daily per capita domestic water use than that of Tianjin. In 1978 when the economic reform was just initiated, Tianjin's daily per capita domestic water use (L/p/c/d) was less than 50% of Beijing's (65.7 L/p/c/d vs. 138.7 L/p/c/d). In 1988, Tianjin's domestic consumption reached 136.1 L/p/c/d, 86% of Beijing's 157.9 L/p/c/d.

By 1998, the gap between Beijing and Tianjin had opened up again, with Tianjin's use at approximately 60% of Beijing's (Tianjin's 144.7 L/p/c/d vs. Beijing's 238.2 L/p/c/d). From 1978 to 1998, the annual average growth rate of per capita water use of Beijing was only 2.83%, while in Tianjin it was 4.33%

Source: 'Understanding urban residential water use in Beijing and Tianjin, China'; H H Zhang and D F Brown, Habitat International 29, (2005)

In creating forecasts of future potable water demand, high and low rates of population growth can be linked with high and low rates of change in per-capita consumption. High, medium and low demand forecasts can be developed.

In many cities, allowances should be made to the requirements of non-domestic users (hotels, restaurants, army barracks and schools). Table 2 is based on information from the USA (Colorado) and should perhaps be seen as the upper zone of demand assessments for this category of user.

Table 2 Non-domestic water use in Colorado, USA

Water User	Lower Bound	Upper Bound	Unit (per annum)
Hotels	3.2	6.7	m^3/m^2 floor area
	115	150	m^3/ room
Restaurants	6.9	8.5	m^3/m^2 floor area
	40	54	m^3/m^2 seat
Schools	0.5	0.8	m^3/m^2 floor area
	6.5	10	m^3/m^2 student

Estimates of actual water consumption are also required, as a large part of potable water supply will be returned to the resource system as sewage effluent in urban areas, or groundwater recharge in rural areas.

Forecasting industrial water demands

Forecasting future industrial water demands requires forecasts of the future mix of industry to be expected in any particular area. Clearly different types of industry have different water needs, and knowledge of local development plans is required in order to forecast demands. National and international economics may influence future industrial growth and it is again important to try and establish upper and lower limits on industrial demand forecasts. It is also important to establish potential for recycling, and the proportion of demand that is consumptive. As with potable water use, actual water consumption by industry is often a small part of the demand, although water may be returned to receiving waters with poor water quality, causing further water resource issues downstream. Both urban water demand and industrial water demand can, however, result in significant and severe localised stress on water resources, and often on the same sources.

Table 3 shows some typical water usage figures based on real situation water audits in the UK. For scenario planning it would be required to assess the status of the water usage efficiency in the locality where the demand estimation is being made. In many situations in northern China, it is likely that the current usage rates are closer to the ‘upper quartile’ values in the table and that the aim would be to improve usage to between the ‘Good’ and ‘Average’ situations. As can be seen from the data, there is a wide variation in usage rates. This shows the uncertainty surrounding the overall process of demand estimation. However, use of such figures within a metered zone where the characteristics of the industrial enterprises are known will enable more typical values to be derived. Additionally, data should be obtained as to the real water use in the water industries through there individual consumption records and these numbers should be compared with the ‘typical’ values in the table. This will indicate what potential improvements are possible.

Table 3: Typical industrial water usage in the UK

Sector	Water Use Units	Water Use Estimates (Annual)					Nr of Samples
		Minimum (Good)	Average	Maximum (Poor)	Lower Quartile	Upper Quartile	
Automobiles	m^3/employee	1	99	409	17	162	13
	m^3/vehicle	2.2	29	159	4.5	28	11
Ceramics	m^3/tonne of product	0.04	12	77	0.35	12	18
	m^3/employee	22	166	474	17	162	20
	Litres/ brick	0.1	0.3	0.6	0.2	0.4	6
Glass	m^3/tonne of product	0.01	11.3	27.5	3.1	20	13
Foundaries (metal casting)	m^3/tonne of product	0.01	17	129	1.1	19.3	34
	m^3/employee	8.3	161	648	41	251	14
Metal finishing	m^3/tonne of product	0.01	7.2	29	0.5	11.7	17
	m^3/employee	13.8	636	1872	173	1048	29
Chemicals	m^3/tonne of product	0.02	28	198	1.8	24	35
Plastics	m^3/tonne of product	0.4	12	66	2.3	8.4	10
	m^3/employee	4.5	33	77	8.1	48.6	6
Paper and Board	m^3/tonne of product	1	29.5	143	9.4	35.8	50
Printing	m^3/employee	3.5	37	143	18.4	34.9	9
Electronic & Engineering	m^3/tonne of product	0.04	9.5	20	5	15	9
PCB Manufacture	m^3/m^2 of finished board	0.07	0.87	7.38	0.31	1.10	40
Leather	m^3/employee	172.5	1462	6042	543	1967	21
	Litres/skin	60	100	170	70	120	4
Furniture	m^3/employee	4.1	125	882	7.9	63	15
Textiles production	m^3/tonne of product	0.1	145	939	18	164	74
Textile finishing	m^3/tonne of product	0.1	146	757	18	185	39
Brewery	m^3/m^3 of product	2.6	7.3	21	5.1	8.4	30
Soft drinks	m^3/m^3 of product	1	3.1	9	1.6	4.3	24
Vegetable & fruit juices	m^3/m^3 of product	2	4.9	14.5	3.0	4.5	7
Dairy	m^3/m^3 of product	0.9	197	2497	?	?	13
	m^3/tonne of product	0.03	164	1786	?	?	18
	m^3/employee	85	857	1781	246	1420	8
Fisheries (processing)	m^3/tonne of product	1	14	53	6	20	27
	m^3/employee	88	260	486	133	359	4
Fruit & Vegetables	m^3/tonne of product	0.1	7.8	39	1	8	14
Meat processing	m^3/tonne of product	1.2	4	16.5	2	6	15
Poultry farms	Litres/live bird	10	20	60	20	20	14

Source: Envirowise (Environment and Energy), UK

It should be noted that each municipality or province has often prepared a list of 'water use norms' for industry. These are often single standard values without the 'knowledge' of the potential variability of use levels. Additionally, many of the water use numbers are related to the product value (i.e. m^3/RMB of GDP or similar). The estimation of water use based on the number of employees (in the Table 3) should be considered with caution since the staffing levels in UK enterprises per unit product output is normally much smaller than in many parts of China.

Industrial water usage also results in wastage. The effluent will possess different levels and form of pollution that must also be considered in the scenario planning process. For example many fruit and vegetable wastewaters are highly acidic. Abattoir waste is high in fat and suspended solids (note blood has a COD of 400,000 to 900,000 mg/litre). Such information should be available from the local EPB office and should be indicated on effluent discharge permits. If there are no effluent discharge permits, field data held by the local EPB office should be obtained or typical values requested from the EPB office to help in any river water quality assessment and planning process. Different scenarios of waste disposal into the natural drainage system should be based on this data.

Forecasting agricultural water demands

Forecasts of agricultural water demands are linked to existing and planned agricultural development in a basin. It is necessary to separate livestock water demands from irrigation water demands and to take into account sectoral development plans and potential changes in cropping. Irrigation may often be the focus of water resources development, and is generally the largest component of water use.

Irrigation water demands are generally built up from a knowledge of existing or assumed cropping calendars and patterns, from knowledge of the hydrometeorological characteristics of the area, of soil conditions, and likely irrigation efficiencies. Agricultural practices can influence water requirements significantly, as can irrigation technologies, and these should be taken into account in developing irrigation demand forecasts. Establishing what happens to irrigation losses is important, as irrigation losses will often be replenishing groundwater, or sustaining vegetation around the periphery of fields or along canals.

In many river basins irrigation is the principal water use, and there will be opportunities to modify that water use by changes in cropped area, changes in cropping, changes in irrigation technologies, and improved irrigation efficiencies etc. Different levels of investment would be associated with these changes, and different levels of financial and economic return would be expected also. It is thus common to investigate a range of cropping and agricultural practices.

Water use norms in irrigated agriculture can be found in all water management government offices. Sometimes there is some disparity between values in different parts of a province and often between provinces. Actual water use per crop between different real situations will inherently be variable since the forms of irrigation, land types and the characteristics of the irrigation system and the management efficiency of the farmer is variable. In many cases, the irrigation water use norms are a little unclear as to assumptions that are inherent in the values. Advisory Note 1.8/2 'Agricultural Water Use Norms' provides further insight into this issue. Often there are different norms applied to setting the value on a water abstraction permit to one that might be used for regional planning. In the case of scenario development the regional planning norms should be used. The assumptions behind these should also be fully transparent if scenarios are to be developed for irrigated agriculture.

The development of irrigation development scenarios will need to encompass, for different planning areas:

- Areas irrigated by surface water systems, areas by groundwater systems
- Crop types and Cropping patterns being irrigated
- Distribution of irrigation types (will commonly be flood irrigation) in each situation
- Conveyance system characteristics and assumed water losses in each situation

These are just the main features on which scenarios will be developed. Hence, the degree to which irrigation norms incorporate the above features needs to be known.

Environmental flows and ecological water requirements

In all river basins there is an 'accepted' requirement for water to be allocated to maintain or enhance the natural environment. Environmental flows in perennial streams are often set at a defined threshold on the flow duration curve, or following a habitat survey and environmental appraisal. There may also be minimum flow requirements to maintain water quality standards. In some areas it is necessary to maintain high groundwater levels to sustain vegetation, and to avoid land degradation. It may be possible under some circumstances to define environmental flows or ecological water requirements as volumetric water demands or allocations, but more often practice is to use environmental flows and ecological water requirements as constraints in resource planning models. There could be a specified minimum river flow below which abstraction for other uses would not be permitted. In relation to groundwater systems, maximum groundwater drawdown could be defined for different zones or for different time periods.

Water managers should be familiar with the requirements for environmental impact assessment of plans under the 2002 Law on Environmental Impact Assessment. MWR have issued guidance relating to environmental allocations and to EIA in the context of river basin planning (see bibliography for details). In the present series of advisory notes there are two relevant documents: Advisory Note 2.4/1 'Environmental Risk Assessment' and Advisory Note 2.4/2 'Environmental Water Allocation'.

Climate change

Climate change will certainly have an impact on water resource availability. The science of climate change is, however, still at an early stage and there is a great deal of uncertainty associated with forecasting potential climate change impacts on water resources. There are uncertainties associated with natural climate variability, with climate sensitivity to CO_2 doubling, with the path that future greenhouse gas emissions might follow. Also there are uncertainties in understanding of the true physical nature of all interacting processes and feedbacks that make up the climate system, and in our ability to model these satisfactorily. In assessing potential future climate change impacts it is therefore necessary to consider a range of plausible scenarios.

Climate change is generally not expected to have a significant impact on potable and industrial water demands. It could have a more significant impact on irrigation water requirements, however. This impact is complicated a little by CO_2 fertilization. Crop models can be used to determine crop yield response and crop water use under climate change. Higher temperatures may result in shifts in cropping patterns, and overall changes in irrigation water requirements. This leads back to a requirement to investigate alternative cropping and agricultural practices under the influence of climate change.

Under the Water Resources Demand Management Assistance Project (WRDMAP) a climate change impact assessment study was carried out for two river basins in northern China, the Shiyang River Basin and the Upper Daling River Basin.

3.3 Strategies for resource development and management

Resource development options

In situations where a water resource is to be further developed, there may be several means by which this can be achieved, and several sequences in which it can be achieved. There may be potential for direct surface water abstraction, for the conjunctive use of surface water and groundwater, for upstream surface water storage, and for some combination of some or all of these options. Where surface water storage is being considered, there will often be different potential dam and reservoir sites to be considered, as well as different dam heights that would result in different levels of reliable yield. Different resource development options will have different capital and recurrent costs, as well as different environmental impacts, and all of these issues must be addressed.

Demand management options

The potential benefits of demand management are three fold:

1. Operating costs and water delivery costs can be reduced, resulting in direct cost savings for consumers and economic benefits

2. The degree of utilization of the available water resource can be increased resulting in improved water productivity

3. Capital investment in major new hydraulic infrastructure can be deferred or reduced, thereby reducing government expenditure

A range of demand management options exists for potable, industrial and agricultural water demands.

Demand management options that could be considered for potable water supply include:

- Leakage reduction and control
- Grey water re-use
- Household water management (low flush systems, low volume shower heads etc., improved white goods water use efficiency)

Box 3 Sustainable water resources development and management scenarios

Sustainable development aims to achieve a better quality of life for everyone now and for generations to come. The needs of the present should not compromise the ability of future generations to meet their own needs (intergenerational equity). Sustainable development is concerned with achieving economic development in the form of higher living standards while protecting and enhancing the environment. The overall aim is to ensure that these economic and environmental benefits are available to everybody.

Scenarios that include significant demand management measures address sustainability issues at the root.

Similar options exist for industrial water demand management, where it is also important to consider the industrial waste water streams. Wastewater treatment and re-use in industrial processing is often a viable option that leads to both more efficient water use and better regional wastewater treatment. It also helps to adhere to the 'polluter pays principle'.

In irrigated agriculture, demand management options could include:

- Canal lining to reduce leakage and improve distribution efficiency
- Changes in crop selection and/or irrigation scheduling to reduce demand / seepage ″losses″
- Adoption of mulching and other agronomic practices
- Changes in cropping that permit changes in irrigation technologies
- Adoption of deficit irrigation practices
- Improved monitoring and water allocation

All demand management options have associated costs and benefits that must be incorporated into the scenario evaluation process. For the most part, water losses remain within the water resource system, except when the losses occur in the form of non-beneficial evaporation. However, this assumes that the water ″losses″ that enter the soil profile are re-usable elsewhere as a groundwater resource ('beneficial'). The benefit could easily be seen as related to environmental condition improvements. Reduction in operating costs may often be the justification for demand management rather than improving resource utilization and water productivity. It is important to maintain a holistic perspective.

Sequencing resource developments

When new resource developments are implemented, they normally result in a stepped increase water supply. The developments are therefore generally sequenced in a way that permits demand forecasts to be satisfied, while minimizing the present value costs of infrastructure development.

3.4 Integrated scenarios

Scenarios are generally developed through the combination of different component demand forecasts, and different resource development strategies. The sensitivity of these integrated scenarios to uncertainty in system inputs would then be evaluated.

The components of a scenario need to be studied to see if they are complementary (preferred) or contradictory/incompatible. These issues need to be understood and brought to the attention of stakeholders. Where 'incompatibility' is considered to exist the components of a scenario may need to be changed.

A progressive scenario approach may avoid the danger of incompatibility.

Table 4 shows an example of progressive scenario development that permits evaluation of the influence of particular components to be assessed.

Once component influences are understood, final evaluation may be made on integrated scenarios, examples of which are given in Table 5 which is based on the Shiyang River Basin – Scenario A in Table 5 will include all the recommendations of the Shiyang Strategic Plan for the 2010 planning horizon (which are listed in Table 6).

Table 4 Example of progressive scenario testing – Shiyang River Basin

Scenario	Description
Reference	This is the 'business as usual' scenario, based on conditions in the 2000-2005 period and depicting what would happen to water resources in the basin if no water resources management interventions are introduced
1A	Reduced irrigation areas by 2010, no changes in irrigation efficiency, no constraint on water duty from groundwater (i.e. no deficit irrigation unless constrained by system limitations)
1B	As for 1A, but including improved irrigation efficiencies
1C	As for 1B, but with revised cropping to reflect the introduction of greenhouses and switch to vegetable crops
1D	As for 1C, but with net water allocation as indicated in the Strategic Plan. These reduced net allocations are achieved through a combination of mulching, improved irrigation technologies and some deficit irrigation
1E	As for 1D, but with maximum groundwater abstraction as indicated in the Strategic Plan
1F	As for 1E, but including the Xiying water transfer
1G	As for 1F, but including the improvements to the Hongshui He transfer
2A	As for 1G, but with irrigated areas and irrigation efficiencies as given in the Strategic Plan for 2020
2B	As for 2A, but with water allocation as given in the Strategic Plan for 2020
2C	As for 2B, but with maximum groundwater abstractions as given in the Strategic Plan for 2020
2D	As for 2C, but including the Dongda River – Caiqi transfer
3A	As for 2D, but with live reservoir storage reduced by 50%
3B	As for 2C, but with inflows reduced by 20%

Table 5 Example from Shiyang IWRM planning in 2009

Scenario	Description
Reference	The reference scenario, representing conditions that would develop were no actions taken to manage water demand.
A	Implementation of the strategic plan recommendations at the 2010 planning horizon.
B	Implementation of the strategic plan recommendations at the 2020 planning horizon.
C	As for B but with reduced upper catchment runoff.
D	As for B but with reduced Yellow River transfer.
E	As for B but with a large area of maize in the middle basin and a large area of cotton in Minqin.

Table 6 Outline of components from the Shiyang River Basin Strategic Plan

Planning year	Components
2010	• Reduction in irrigated area (19%) • Improved irrigation efficiencies (48% to 43% at basin scale) • Reduced irrigation water allocation through mulching and improved technologies • Construction of the Xiying River to Caiqi water transfer • Improvement of the Yellow River to Hongshui He water transfer

In many cases a scenario comprises a number of often interacting components, and it is important to understand the relative importance of these components to the final outcome of a scenario. This would normally be done by incrementally introducing each scenario component and evaluating the incremental effects that each component brings to the selected scenario evaluation criteria.

Scenario analysis can be undertaken with or without simulation modelling. If a simulation model is not used, scenarios will need to be simplified and analyses will be more subjective and more approximate. Nevertheless, a good analysis and reporting can still be useful (essential) in the planning process.

4 Scenario Evaluation and Modelling

4.1 Scenario modelling

It will generally be the case that a simulation model is used to evaluate alternative scenarios. In IWRM a systems simulation model is generally more informative and permits greater understanding of the resource system and its sensitivities.

Figure 3 illustrates the position of a model (and modeller) in the process of scenario analysis. It can be seen immediately that the various modelling tools used in the scenario analysis serve to provide the planning team with material for the scenario evaluation rather than the final product.

Pre-processing

This covers all activities undertaken by the modeller to prepare input data so as to correctly simulate the desired scenario conditions.

The modeller may receive scenario conditions in quite general terms and have to interpret these in order to set up the scenario for a simulation run. If there is a problem in conceptualising the scenario conditions this should always be referred back to the water resources team.

Box 4 Setting up a scenario

Example: a scenario calls for a 40% increase in the area under greenhouses

For every model node with an existing agricultural demand the following questions must be answered:

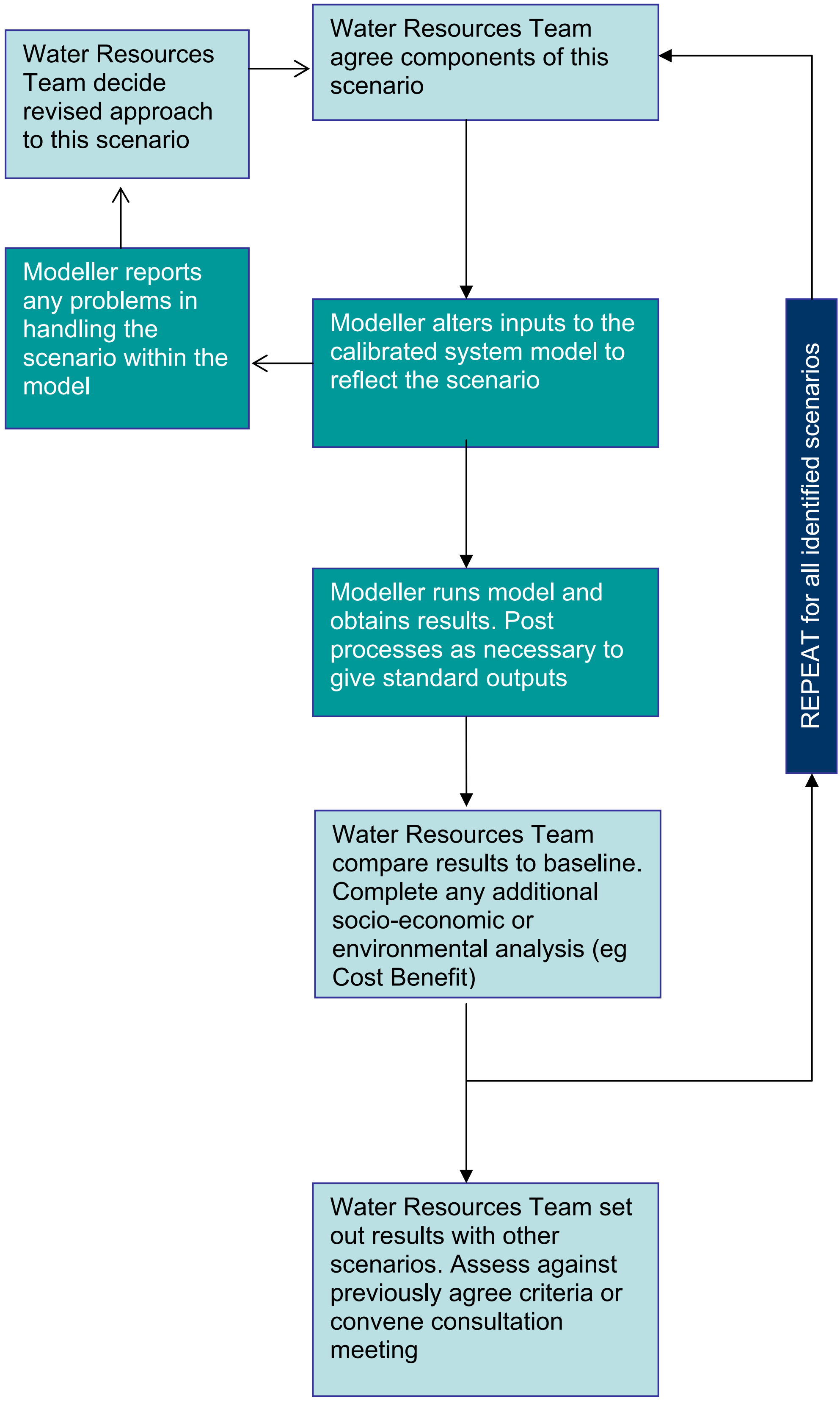
- Any change at this node (Y/N)?
- What is the new cropping pattern?
- What is the new norm or efficiency for greenhouse cultivation?
- Any other changes in agricultural practices as a result of the switch to greenhouses?
- Any change to costs or value production?

When modelling scenarios, many elements of the data may be embedded in the modelling system – demand estimates, changes in cropping, changes in economic and financial data etc. Changes in physical infrastructure, such as the introduction of a new reservoir, or an irrigation area may require a change in the model network. For example, in the WEAP model it is possible to change physical infrastructure properties with time – a network could be created with a reservoir that has no storage in scenarios for which it is not required for example. The WEAP model thus permits all scenarios to be managed within the same database system. (The same is generally true for other proprietary software packages).

It is important to judge / estimate the model sensitivity to particular interventions (or scenario components). Understanding this model sensitivity is important to the modeller and also to the ″water resources team″. Additionally, determining the best way to represent something like extensive mulching may need to be accompanied by a dummy crop type that has assigned to it a reduced water demand, or the introduction of an alternative set of crop coefficients. Again model sensitivity to such dummy, or perhaps proxy approaches, needs investigating and needs to be understood by all.

In the Shiyang River Basin, extensive winter irrigation is practiced, when no crops are in the ground. Much of the water applied becomes frozen in the upper soil horizons during the winter, and is available in the spring when the ground thaws. Representing this in a model can be difficult, and in the WEAP application involved the introduction of dummy additional demand nodes and temporary groundwater storage nodes to represent water frozen in the soil.

Figure 3: Role of modelling in the scenario analysis process



The interpretation of scenario components needs to be well documented. A planned intervention could be the investment of YX million in canal lining. This must be translated into so many km of canal lining in a particular area. In order to assess the water related impact this then needs to be seen as a reduction of x_1 $m^3/s/km^2$ of wetted perimeter. This then needs to be related to a pre-intervention loss factor of x_o $m^3/s/km^2$ to indicate a % reduction in losses from the canal moving to deep seepage and evaporation.

After setting up, and most importantly, checking the details are correct, the modeller can run the water resources modelling tools (eg WEAP) for the selected scenario.

Post-processing

Available systems simulation software varies in the degree of analysis and format of outputs offered. A model such as the WEAP model can provide a variety of results on the performance of individual resource system components, supply reliability, crop yields, net income, operating costs, net present values etc. Other packages may, for example, lack facilities to carry out economic analysis.

Post-processing comprises all aspects of further analysis, any reformatting to achieve a particular presentation style, the recording of all characteristics of the scenario and all data sets used, and the archiving all digital files and records that would be required should a repeat run be required at a later date. A systematic process for this is important.

Evaluation

There is seldom a single evaluation criteria used in scenario analysis. Typically, evaluation criteria would include stress on the water resource, degree to which demands are met, financial performance, economic performance, resilience, environmental sustainability and impact, social impact, levels of service etc. The criteria are usually determined in conjunction with stakeholders early in the planning cycle (see Section 2.2).

The water resources team carry out the evaluation in accordance with the agreed criteria. However, an important part of the evaluation process is a check of the model outputs. Any unexpected model results should lead to a detailed audit of the input conditions or to the manner in which the scenario was conceptualised for modelling purposes.

For an individual scenario the results should be compared to the baseline or current condition in terms of water available for different users throughout the basin, and the environmental and socio-economic impacts, both positive and negative, assessed.

It is important to assess model sensitivity to the various assumptions that are inevitably made in its parameterisation. It is equally important to assess the sensitivity of results and of overall benefits to different elements of a scenario, recognising of course that the model may not identify all benefits. Increasing irrigation efficiency from 60% to 70%, may not have a tangible benefit in terms of crop production or reduced operating costs, and could have a high investment cost, but may have intangible benefits through the release of water for environmental needs that are difficult to quantify.

Finding appropriate means of results presentation to the full range of stakeholders is thus very important, and may not be easy.

The results should be presented in standardised map, graphical and table formats that are used for all scenarios (so that different scenarios can easily be compared against the baseline and against each other).

All assumptions made in the environmental and socio-economic analysis for a scenario test should be recorded in a standard format and attached to the evaluation report.

A brief overview of using the WEAP model in the Shiyang River Basin is given in Advisory Note 1.3 'Using the WEAP Modelling Software'.

4.2 Presentation of the results of scenario analysis

The output format should be determined by the critical issues in decision making and in communication with stakeholders.

It is very important to address the 'presentation of results' issue because scenario analysis can be very complex and difficult to successfully communicate to non-modellers and non technical stakeholders. A well chosen presentation format is one that is readily understood. Maps and time series presentation are likely to be particularly useful from this perspective. Utilisation of a GIS facilitates this process. However, care must be taken not to over-complicate otherwise key messages will be lost. Additionally, if the presentation of results is too complex stakeholders may disregard the process since they think it beyond their understanding. The better the presentation style / format the more comments and views from stakeholders are likely.

Examples of output formats

The following examples are taken from IWRM plans developed for the Shiyang River Basin and for the Upper Daling River within Chaoyang Municipality. They illustrate a variety of table, graphic and map output styles, although clearly other formats might be more suitable in a different situation. They were designed largely for a professional audience and publication in a plan document; they would need to be redesigned if the results were intended for presentation to a wider stakeholder group.

Table 7 illustrates a typical summary table style. The values of two economic performance indicators are compared over a range of scenarios (including the reference or baseline) and for a list of different irrigation schemes in the Shiyang River Basin. It is therefore possible to identify the most effective scenario (in terms of these two indicators) for a particular scheme or for the entire list, or to rank schemes in the list under a particular scenario.

Figures 4-6 illustrate alternative graphic styles. All three are time-series and compare the performance of different indicators for several scenarios. Figure 4 presents monthly variation, Figures 5 and 6 show annual information over a long-term simulation. In all the figures comparison can be made against the reference scenario.

Figures 7 and 8 illustrate map output styles. Maps can be a very powerful method of presenting results but care must be taken not to overcrowd the map so that it becomes difficult to understand.

Table 7 Example comparison of economic consequences of different scenarios (Shiyang River Basin)

				Average Annual Net Crop Production Value per Ha (Y/ha)						Average Net Crop Production Value per m3 of Water (Y/m3)					
Irrigation area	Irrigated Areas by Scenario (ha)			Scenarios						Scenarios					
	Reference	Scenario A	Scenarios B-E	Reference	A	B	C	D	E	Reference	A	B	C	D	E
Baqu_GW	18,382	11,547	11,547	9,281	9,718	10,907	10,907	10,907	12,848	1.39	1.37	1.58	1.59	1.60	2.09
Changning GW	6,100	1,527	1,527	7,937	8,704	9,096	9,096	9,096	11,928	1.21	1.19	1.25	1.25	1.25	1.77
Dajing Irr	6,960	6,960	6,960	6,002	5,985	8,207	8,082	8,207	8,235	2.55	2.55	3.56	3.73	3.56	3.67
Donghe Irr	17,781	12,597	7,092	3,853	5,413	5,776	5,613	5,775	5,644	1.68	1.19	1.29	1.32	1.29	1.31
Gufeng Irr	1,960	1,960	1,960	4,886	4,892	6,214	5,954	6,214	6,255	2.49	2.48	3.08	3.42	3.08	3.17
Gulang Irr	8,920	8,920	8,189	6,287	6,287	7,220	7,220	7,220	7,220	2.17	2.17	2.55	2.55	2.55	2.71
Gulanghe Irr	9,687	9,687	9,687	5,722	6,014	6,888	6,818	6,887	6,889	2.42	2.28	2.58	2.61	2.58	2.75
Huangyang Irr	9,560	8,139	8,139	6,937	7,104	9,167	9,099	9,166	10,187	1.55	1.52	2.02	2.08	2.03	2.55
Huanhe GW	5,207	2,654	2,654	7,320	7,605	8,128	8,128	8,128	8,154	1.24	1.24	1.34	1.34	1.34	1.49
Hubei Irr	10,957	6,903	6,903	9,508	8,644	10,867	10,758	10,809	12,888	1.17	1.28	1.51	1.52	1.58	2.05
Hunan Irr	7,071	4,455	4,455	9,508	8,644	10,867	10,758	10,809	12,888	1.17	1.28	1.51	1.52	1.58	2.05
Jiahe_GW	2,698	1,700	1,700	9,470	9,718	10,906	10,906	10,906	12,857	1.39	1.37	1.58	1.59	1.60	2.11
Jinchang Irr	12,207	12,207	7,266	4,594	8,085	9,764	9,764	9,764	9,764	1.74	1.46	1.73	1.75	1.73	1.76
Jinta Irr	8,227	8,227	8,227	7,686	7,744	9,784	9,597	9,781	10,620	1.46	1.44	1.89	1.95	1.89	2.24
Jinyang GW	8,227	8,227	8,227	7,340	7,518	9,988	9,988	9,988	11,317	1.59	1.71	2.41	2.41	2.41	2.93
Nanhu GW	1,523	1,523	1,523	7,822	7,807	7,953	7,953	7,953	7,953	1.30	1.29	1.32	1.32	1.32	1.37
Qinghe GW	16,134	10,518	8,388	9,564	9,729	9,774	9,774	9,774	9,681	1.43	1.43	1.70	1.70	1.70	1.75
Qingyuan GW	11,881	11,881	11,881	8,283	6,730	8,428	8,428	8,428	9,796	1.27	1.15	1.49	1.49	1.49	1.73
Quanshan Irr	20,225	12,724	12,724	8,059	8,121	9,901	9,834	9,862	12,849	0.99	1.13	1.33	1.34	1.38	1.98
Siba Irr	6,947	6,947	5,081	4,479	4,932	5,514	5,338	5,403	5,532	1.49	1.29	1.29	1.34	1.32	1.24
Xihe Irr	16,434	16,434	6,727	4,157	4,740	5,707	5,651	5,704	5,632	1.39	1.19	1.19	1.23	1.19	1.16
Xiying Irr	25,568	21,937	21,937	7,952	7,261	8,460	8,271	8,458	9,363	1.51	1.38	1.59	1.63	1.59	1.84
Yongchang GW	11,167	11,167	11,167	6,816	6,780	8,609	8,609	8,609	8,431	1.07	1.09	1.42	1.42	1.42	1.74
Zamu Irr	23,855	20,225	20,225	7,027	7,450	8,800	8,620	8,798	9,371	1.44	1.38	1.65	1.67	1.65	1.97
Total / Mean	**267,678**	**219,066**	**194,186**	7,119	7,174	8,724	8,639	8,714	9,550	1.39	1.38	1.66	1.68	1.67	1.97

Note: In this case the WEAP modelling software was used and this has economic analysis as an integral part of the modelling, scenarios defined as in Table 5

Figure 4 Seasonal irrigation supply - average conditions after 30-year simulation

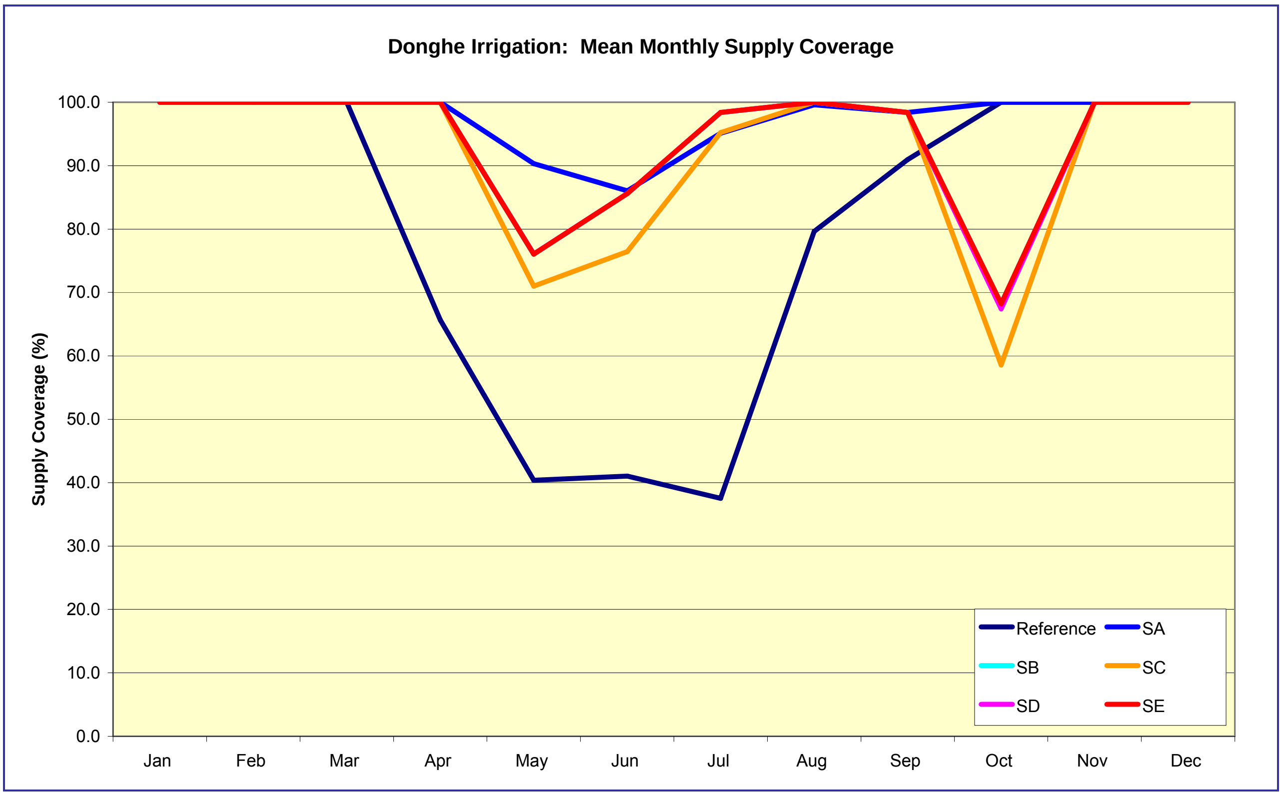


Figure 5 Inter-annual variation in crop production over 30-year simulation

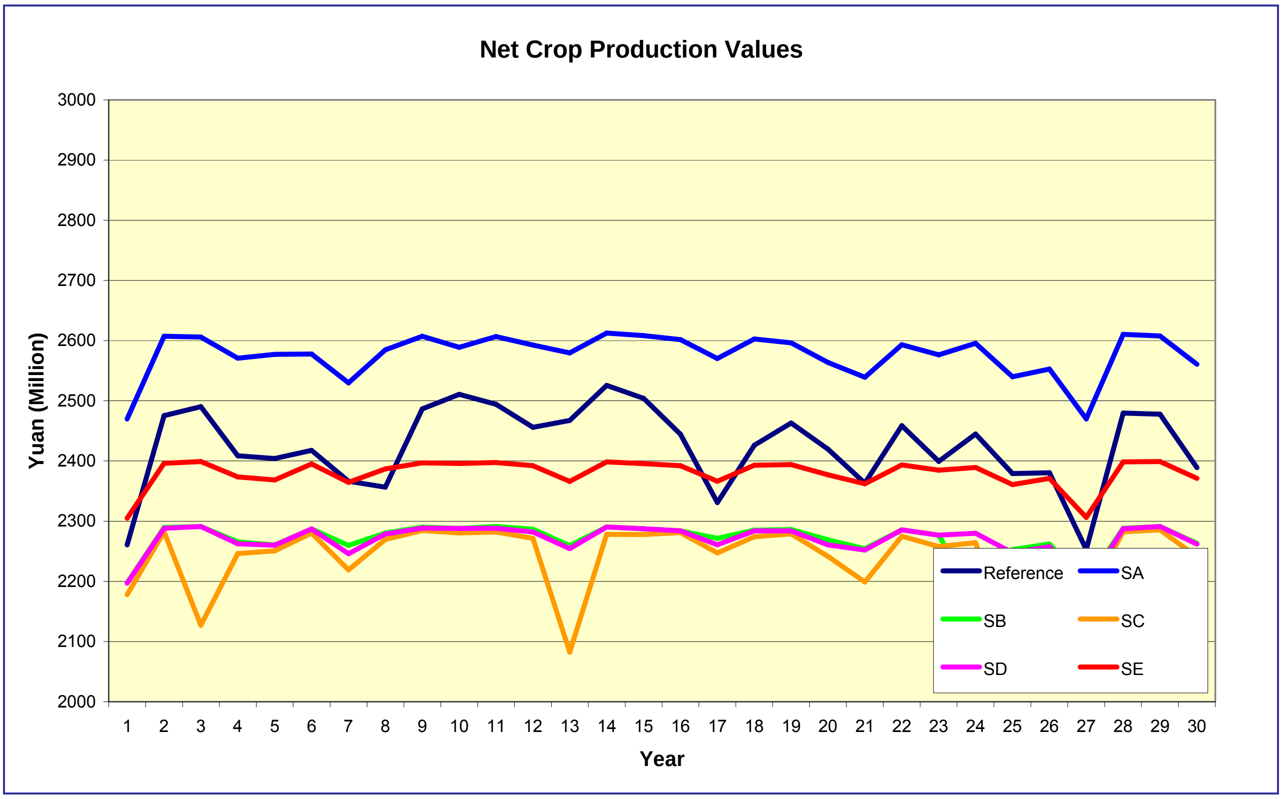


Figure 6 Inter-annual variation in shortfall to supply a group of schemes

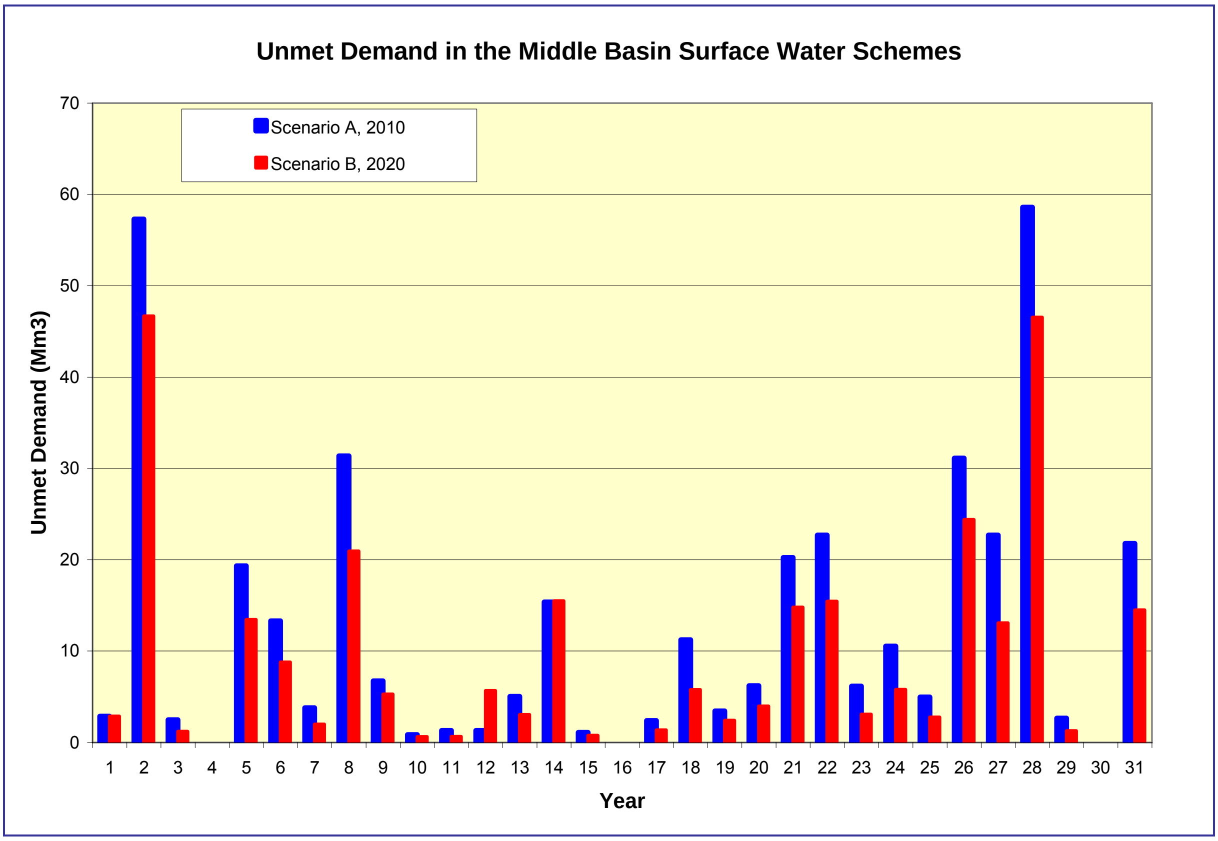


Figure 7 Relative irrigation demands and sources of irrigation water supply

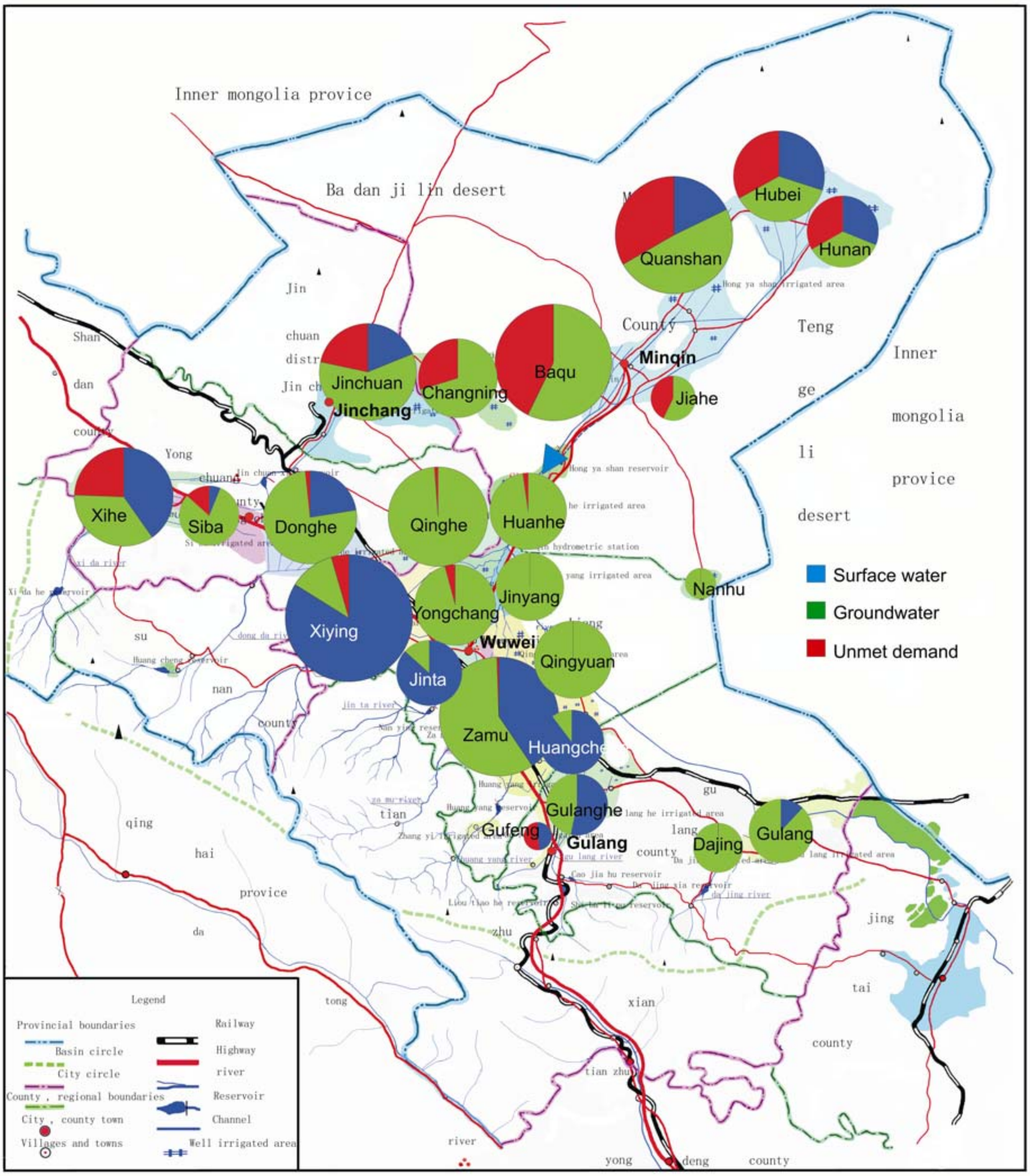
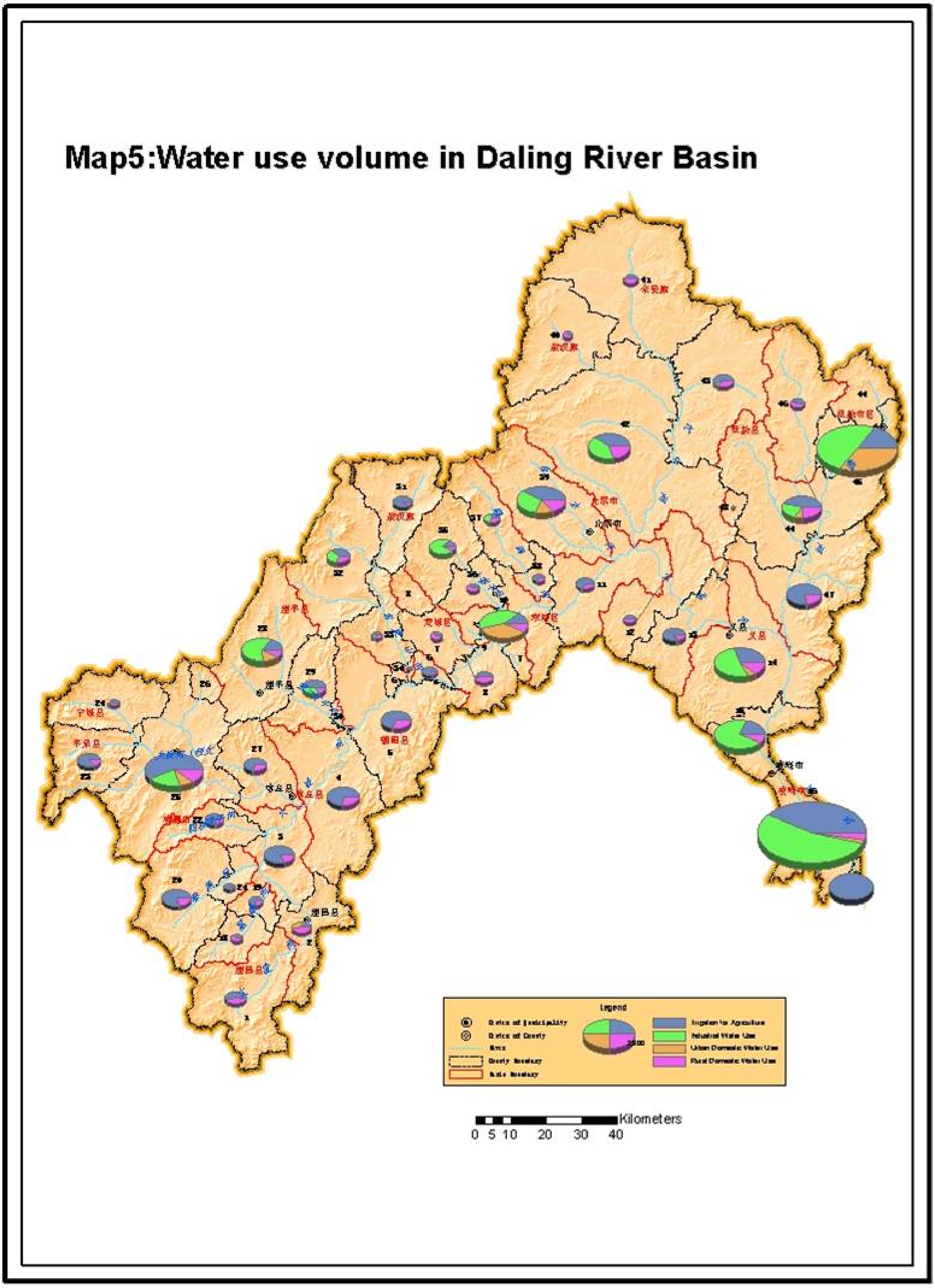


Figure 8 Water use volume by sector



Document Reference Sheet

Glossary:

Performance indicator	A parameter to be monitored over time to help managers assess the success of an intervention, chosen for its sensitivity to the intervention
Scenario	A projection of how the future may unfold based on current information, one of several detailed plans or possibilities
Polluter pays principle	Principle according to which the polluter should bear the cost of measures to reduce pollution according to the extent of either the damage done to the environment and society or the exceeding of an acceptable level (standard) of pollution

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Document Reference Sheet

Related materials from the MWR IWRM Document Series:

Advisory Note 1.1	Models for Water Resources Planning and Management: Selection Procedures
Advisory Note 1.3	Using the WEAP Modelling Software
Thematic Paper 1.8	Water Demand Forecasting
Advisory Note 1.8/1	Water Demand Forecasting
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Advisory Note 2.4/1	Environmental Risk Assessment
Advisory Note 2.4/2	Environmental Water Allocation
Thematic Paper 7.1	Multi-criterion Decision Analysis – an Introduction

Where to find more information on IWRM – recommended websites:

Ministry of Water Resources: www.mwr.gov.cn

Global Water Partnership: www.gwpforum.org

WRDMAP Project Website: www.wrdmap.com

China – UK, WRDMAP

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