Chapter Three

Water Resources Management
3.1 Definition of water Resources Management:
The integrated water management is best accomplished within a river basin or watershed. For any water resources utilization to be effective and efficient, it is necessary that the resources of a basin are managed in an integrated manner. By definition, the basin level systemic management is essential for the integrated water resources management (IWRM) principle to succeed. In other words, it is essential to take a holistic approach to IWRM. The decisions on IWRM must be participatory, technically and scientifically informed, and taken at the lowest appropriate level, but within a framework at the catchments, basin and aquifer level which are the natural units by which nature manages water.

For holistic river basin management (RBM), governments should set up management agencies at the basin level. There is a clear hierarchy in spatial domain: catchments, basin, sub-basin, etc. and each is nested within the larger one. The functions of the basin agencies must also reflect that hierarchy, with decision-making pushed down to the lowest appropriate level. It is equally imperative that decision making must be informed and scientifically and technically sound. Effective river basin management, thus, walks on two legs: (i) parliaments where users make policies and decide on the raising and spending of money, and (ii) competent technical agencies which provide the parliaments and users with the raw and processed information necessary for management.

Experience also shows that major improvements can and have been made in the way in which water is managed. Participatory river basin management has become a reality in some countries. Due to various measures, per capita quantity of water used has actually declined in a few cases over the past decade. While serious water problems persist in rich countries, the situation is far more challenging in developing countries. On almost all counts - service coverage, scarcity and water quality - poor countries have much worse conditions, and they have rapid growth in demand for municipal uses, for agriculture, to industry and for the generation of electricity. Still worse, these countries have only a fraction of the financial resources available compared to industrialized countries.

Water resource management consists of following major steps:
1. ~ Assessment - Of water resources
   a) Uses, needs,
   b) future demands
   c) Disasters
   d) Financial capabilities and constraints
   e) Technical options
2. ~ Planning - Scaling, Sizing, Selecting, Sequencing, Scheduling
3. Design - Structural design, costing, tender documents
4. Implementation - Construction, Supervision, Enforcement of laws ~
5. Operation - Monitoring and regulations of system performance ~
6. Maintenance - Control, repair, replacement
Treating the complex problem, the multiplicity of goals and alternatives requires a logical procedure which can rationally eliminate alternatives, and reduce thousands of decisions to a relatively few. All this should be on the basis of rather formidable mass of information in various stages of scientific interpretation. The conventional methods for development and management of water resources are often not suitable for handling complex problems of planning and management of water resources at the river basin level. Systems engineering is a very powerful technique for quantitative analysis of the planning and operational problems of large river basins, since it allows consideration of complex issues in their totality.

**Figure 3.1** Major Roots Causes of Water Resources Problems and Their Effects

Water is already fully allocated and exploited in many basins. Gradually many basins are inching towards this distinction. Therefore, the elbow room for water resources development is shrinking and in future people will have to work within tighter constraints. Planning helps in assessment of the present status in the basin, the situation desired the gap between the two, and the means to bridge the gap. It also helps to set priorities. Second, it is often not possible to do policy analysis and organize public participation for each individual decision. In such cases, planning offers a framework and focus. Third, open and participatory planning processes will result in more public support or acceptance of the resulting plan/policy and (by extension) operational management. Fourth, planning may have a co-coordinating effect by bringing the different river basin managers into close interaction with each other.
The formulation of the objectives is an initial step in the planning and developmental process. The systems approach demands an explicit articulation of the objectives in the form of an objective function by which the output of the system can be determined, given the policy, the initial values of the state variables, and the system parameters. Systems analysis for water resources projects planning is carried out with the basic objective of meeting certain fundamental requirements in an optimal way, by satisfying some economic or other criteria of optimality. The task of water resources systems planning may be to plan new water resources projects, or to plan enlargement of a system.

**3.2 Functions of Water Resources Management**

Management of the water sector generally comprises four groups of functions as demonstrated in Figure 3.2:

1. Assessment and development of water resources (groundwater, surface water, non-conventional water sources) to augment and enhance availability of water.
2. Allocation of available water resources to the competing groups of water users (municipal, commercial, industrial, agricultural).
3. Utilization of water by the various water users (delivery, consumptive use, and waste generation).
4. Environmental protection and pollution control for safe integration of waste in the water cycle and recycling.

Employing a combination of these groups of functions, water managers try tirelessly to strike a balance between the available water resources and the demands on water by either:

- Supplying more water (supply management or augmentation) to match the perceived rising demands focusing mainly on the assessment and development of new water source and supply facilities.
- Manipulating the demand on water (demand management) to match them with available supplies focusing mainly on the other three groups of functions namely: efficient allocation; efficient water utilization; and effective pollution control and recovery of wastewaters.
Historically, water resources policies and management practices have been supply driven. To meet the perceived rising demand, intensive efforts were invested in the assessment and development of new water sources and installation of delivery systems with little or no attention to the other three groups of functions. The main outcomes of the supply approach are the utilization of freshwater sources beyond their renewable capacity leading to their depletion. Nearby and better quality sources are first used. Distant sources are sought at higher cost. Nonrenewable groundwater is mined, and lesser quality water is used. When we run dry, we turn to the sea.

As the demand on water goes unchallenged so does the production of waste. Water management practices historically paid little or no attention to safe management of the huge volumes of wastewater produced. The collection and disposal mind-set prevailed because of concerns over public health protection. Cesspits were built to make wastewater disappear in the ground. Water intensive and centralized sewer systems were built to remove wastewater from the immediate environment of the communities using water as a transportation medium. When rivers, lakes, and accessible groundwater became polluted, wastewater treatment plants were built. Yet, a significant proportion of the scarce water sources continue to be consumed by pollution and the much needed water conservation drives can not be accommodated because of the intense water requirements for flushing the sewers. Recent trends in water resources management indicate that water is increasingly recognized as: a valuable resource for the health and well-being of the society and its sustainable
development; a finite resource which must be used efficiently and wisely; a renewable resource which must be kept clean and its quality protected; and a shared resource which must meet the needs of competing current users (humans and non-humans) and future generations.

There is increasing recognition that no supply strategies can keep pace with the present rate of population growth and demand even in the water-rich and economically-enabled countries. Water management practices now explore demand management solutions to ensure optimal, efficient, sustainable, and beneficial use of water. Allocation between the competing water users is used to ensure that the water use pattern supports the public interest with emphasis on meeting the basic human needs for domestic water supplies. Water efficiency solutions are adopted to minimize the wasteful consumption and reduce the consumptive use of water. Environmental protection and pollution control policies are considered within the framework of integrated water resources management. Wastewater is being considered within the total water cycles and pollution control policies not only aim at stopping the pollution of the scarce water sources but also maximizing recycling and reuse of wastewater within the water budget of the households, communities, industries, commercial establishment and agriculture. Decentralized wastewater management is being explored for greater protection and many more opportunities for reducing the nonproductive consumption of water in waste transportation and maximizing the recycling opportunities.

3.3 WATER RESOURCE SYSTEM ANALYSIS

A system may be defined as a set of objects. Which interact in a regular, independent manner. A system is characterized by: (i) system boundary which is a rule that determines whether an element is to be considered as a part of the system or of the environment; (ii) statement of input and output interactions with the environment; and (iii) statements of interrelationships between the system elements, inputs and outputs, called feedback. Depending upon the level of detail used to model the system components, appropriate hydraulic and hydrologic equations are used to describe the flow relationships between system components. For example, a continuity equation is always used to describe the flow balance within a water system. The relationship of water quality for a system component would depend upon the nature of that component and its impact on water quality of incoming flows. One of the main task of a water resource engineer is to modify the inputs to a water system so that desirable outputs are maximized while desirable outputs are minimized. The figure below represents a typical relationship of inputs and outputs in a feedback system.
System engineering is concerned with making decisions with respect to those aspects of a system on which some control can be applied. Systems engineering was defined by Hall and Dracup (1970) as "the art and science of selecting from a large number of feasible alternatives, involving substantial engineering content, that particular set of actions which will accomplish the overall objectives of the decision makers, within the constraint of law, morality, economic resources, political and social pressures and laws governing the physical life and other natural sciences". Thus systems engineering is useful in making selections from a large number of alternatives by way of elimination.

The theories and methods used in systems engineering are termed as systems analysis. Applied systems analysis is a general term including fields like operations research, decision-theory, benefit-cost analysis, planning and scheduling, design, theory of information, application of artificial intelligence in management, and decision-making.

The concept of state is the basic concept of the systems theory. The state represents the conditions of the system or is an indicator of the activity in the system at a given time. In case of water resources systems, the state typically may be the volume of water in the reservoir, or the depth of flow of the river, or the head of ground water at a location.

Systems analysis, as applied to water resources, is a rational approach for arriving at the management decisions for a particular system, based on the systematic and efficient organization and analysis of relevant information. The use of systems techniques requires computers and therefore the application of systems analysis to water resources problems started only with the computer age in early 1960s.

3.3.1 System Analysis Techniques

Systems analysis techniques do not merely deal with the engineering aspects of water resources development but also cover a multi-disciplinary approach encompassing physical, social, economic, political, biological and other characteristics of specific problems and situations. This powerful technique enables evaluation of alternative development scenarios. Mathematical analysis of water resources problems using systems approach is one of the most important developments in the water sector. The systems techniques can be grouped under four major categories as follows:

a. Analytical optimization models and techniques
This group includes optimization methods - they may be based on classical calculus and Lagrangian multipliers or mathematical programming and control theory. The mathematical programming techniques include linear, non-linear, and dynamic programming, goal programming, and multi-objective optimization.

b. Probabilistic Models and Techniques
This group of techniques includes the techniques for analysing stochastic system elements with appropriate statistical parameters. It encompasses all the descriptive techniques of stochastic processes to study the behaviour of some aspects of the system.
The important techniques in this group are the queuing and inventory theory which are concerned with the study of queues or waiting times and inventory stocks.

c. Statistical Techniques
This includes multivariate analysis and statistical inference. The techniques of multivariate analysis, including regression and correlation, factor analysis, and principal component analysis have numerous applications in the water resources area.

d. Simulation and Search techniques
Simulation is a descriptive technique. A simulation model incorporates the quantifiable relationships among variables and describes the outcome of operating a system under a given set of inputs and operating conditions. Simulation models usually permit far less drastic simplification and approximation than is required in an analytic optimization model.

Often a simulation model is run many times with various input and parameter data. The output of these runs describes the response of the systems to variations in inputs and parameters. If the simulation model includes an objective function, the values of the objective for the several runs generate a response surface.

3.3.2 ISSUES IN WATER RESOURCES SYSTEM ANALYSIS
Naturally occurring water can be described in terms of the quantitative availability of water as a function of time and location and the quality of water as a function of time and location. Thus, time t and location x represent the independent variables and quantity Q and Quality V represent the dependent variables. S is used to define the state of the system, which can be represented as

\[ S = [Q(x, t), V(x,t)] \]

The development of water resources deal with the transformation of the natural state of the system into a desired state \( S^* \), which is a function of the desired quantity \( q^* \) and the desired quality \( V^* \), which are both a function of the desired time \( t^* \) and the desired location \( x^* \). The desired state can then be expressed as

\[ S^* = [Q^*(x^*, t^*), V^*(x^*,t^*)] \]

Evaluation of \( S \) and \( S^* \) is within the scope of water resources engineering and requires the combined knowledge and use of hydrology and hydraulics. This involves the transformation of \( S \) into \( s^* \) using

\[ S^* = WS + E \]

where, \( W \) is the transfer function between the input \( S \) and output \( S^* \) and \( E \) represents a waste or bye-product that is undesirable.

The Transformation function \( W \) can be divided into the physical or hardware component \( (W_I) \), like construction of dam, etc., and the operational aspects or software component \( (W_v) \), like the operational policy, etc.
The major problems that must be solved for better water resources management are:
1. Determining the optimal scale of development of the project;
2. Determining the optimal dimensions of the various components of the system; and
3. Determining the optimal operation of the system.

3.4 Water Scarcity and its Impact

Water scarcity is regarded one of the main constraints to social and economic development and even a source of insecurity. Municipal water supplies are becoming increasingly insecure and their quality is degrading. Water Scarcity means that supplies are interrupted routinely and rotated due to severe water shortages especially in the summer. Intermittent water supplies, accompanied by severe water quality deterioration, are common and so are outbreaks of water borne diseases.

Water scarcity is the most significant constraint to the extension of safe water supply services to needy communities. In the West Bank, for example, providing a water supply system to a community is a question of finding the water source, before the question of the funding for the system construction. Many new and existing water supply schemes in Palestinian communities remain without running water for extended periods of time.

In the absence of irrigation water, farmers turn to untreated or partially treated wastewater for food production with significant public health implications.

3.5 Water Shortages vs. Water Management

Understanding the causes of the water shortages is a prerequisite for developing effective water resource management strategies to avert further decline in the water availability. The water shortages in the region are a result of structural and non-structural conditions (Figure 3.3):

1. Structural conditions related to geographic location, climatic characteristics and the population growth. Water policies and management practices can impart little influence on these conditions, at the least in the immediate and near future.
2. Non-structural conditions or management-induced conditions brought about by existing water policies and management practices. These conditions can be changed and their impact reduced through improved water management policies and practices.

3.5.1 Structural conditions causing water shortages

Water scarcity is largely due to natural causes. Our region’s climate is arid and semi-arid characterized by low and erratic rainfall.

The rapid decline in the per capita availability is a result of the rapid population growth, urbanization and socioeconomic development.
3.5.2 Management induced conditions causing water shortage

The water shortages are aggravated by the way water is utilized. Water is often used wastefully, unwisely and inefficiently by the agriculture, municipal, industrial and commercial users. Irrigated agriculture is the biggest water user. Meanwhile, municipal and industrial demands are on the rise and there is not enough water available to them. Cities are running dry and their water supplies are increasingly becoming insecure.

Figure 3-3 Structural and Non Structural Conditions of Water Shortages.


Water is inefficiently used. Water utilization by all water user groups is characterized by great inefficiencies, in the water delivery systems and during utilization. Losses from municipal water delivery and supply systems reach as high as 60% (Figure 3.4) exceeding the quantity of water reaching the consumers. In agriculture, as much as 50% of the produced water is lost during production, storage, and conveyance. Once water reaches it intended target, it is used inefficiently as consumers have no incentive to conserve. Domestic and agricultural supplies are subsidized and the cost to the consumer is far below the real cost of water. Low pricing encourages wasteful consumption of water and offers no incentives to conserve and invest in water efficiency solutions. Inefficient and water wasting fixtures are widely used and public building are water wasters. Best quality water is used in ornamental gardening. In agriculture, water is often used on land and crops with low productivity and low added value on using water. Irrigation methods are inefficient. Flood irrigation efficiency is barely 30%. Water is used for producing export crops even in those countries with the lowest water availability. Exporting crops is effectively exporting the water needed to produce them.
3.5.3 Excessive abstraction and depletion of water resources

The supply-driven water resources policies exacerbated the water shortages in the region. Paying minimal attention to water use inefficiency, countries intensify their search for new water sources to meet the rising demand on water. Groundwater and surface water resources in some of these countries are shrinking to crisis situation and their quality is degrading.

3.5.4 Insufficient and inefficient pollution control

Pollution continues to be a serious threat to public health and a significant freshwater consumer. Water management practices in our region continue to pay little attention to safe management of the huge volumes of wastewater generated. The main sources of pollution are:

1. Unsafe management of domestic wastewater (disposal of untreated or poorly treated wastewater and seepage from poorly constructed and maintained onsite sanitation systems). Existing urban wastewater systems are insufficient and inefficient and in many cases they aggravated the problems they were built to solve.
2. Uncontrolled disposal of industrial waste into sewers, land and water bodies
3. Leaching from unsanitary solid waste landfills
4. Seepage from agrochemicals (excessive use of fertilizers and pesticides)

3.6 Water Resources Management in Palestine

3.6.1 Introduction

The Palestinian Water Authority (PWA), established in 1995, serves as the primary regulatory agency governing the Palestinian water sector. By its own definition (PWA, 2000), the roles and responsibilities of the PWA include:

- Secure Palestinian water rights.
- Strengthen national policies and regulations.
- Build institutional capacity and develop human resources.
• Improve information services and assessment of water resources.
• Regulate and coordinate integrated water and wastewater investments and operations. Enforce water pollution control and protection of water resources.
• Build public awareness and participation.
• Promote regional and international cooperation.

In an effort to fulfill these roles and responsibilities, the PWA has successfully developed a visionary National Water Plan, drafted and ratified a comprehensive National Water Law, and organized a National Water Council charged with providing ongoing guidance to water sector development.

Figure 3.5 indicates the role of the PWA in the Palestinian water sector. Furthering their role as the regulator of the water sector, the PWA engaged in an effort to develop an integrated water resources management plan (IWRMP, 2002) for the West Bank which achieves consensus stakeholder objectives, quantifies resources and demands, confirms strategic principles for sector development and identifies specific actions for achieving stated objectives.
3.6.2 Water Supply and Demand

Water resources management planning efforts included extensive study of the present (2001) supply of water to the West Bank as well as present and future demands for water. The study showed that there is a “gap” between 2001 supply and 2001 demand of approximately 70 million cubic meters (CH2M HILL, 2001). This existing gap consists primarily of agricultural demand that cannot be met with present supply. Dependent upon the assumptions used in forecasting water demand, the “water gap” in the West Bank is projected to exceed 450 million cubic meters per year by 2025 if new supply is not developed and further demand management is not implemented. Figure 3.6 illustrates the baseline West Bank water supply in comparison with one suggested projection of future water demand (CH2M HILL 2002). This projected shortfall in supply has driven policy development and planning efforts in the West Bank and helped to define the strategic principles guiding West Bank water management efforts.

Figure 3-6 Comparison of Existing Water Supply with Baseline and Forecasted Water Demand in the West Bank

West Bank Water Resources Management Strategy

The goals, objectives, standards, policies, and priorities identified and clarified by the stakeholders during integrated water resources management planning (CH2M HILL, 2001) provide elements of a water management strategy in the West Bank. These principles and their implications toward water management action are described briefly below.

- **Resource Management**

The resource management strategy in the West Bank is defined by the word sustainable. In general, sustainable management of a resource provides for long-term exploitation of the resource up to or below a level at which adverse conditions may occur. West Bank water sector stakeholders have explicitly stated their goal of achieving sustainable management of water resources. This goal is a key principle of
the West Bank water resources management strategy and has implications toward management actions that must be taken in the development of the West Bank water sector. Specifically, aquifer sustainable yields must be well understood and aquifer management plans defining specific well abstraction scenarios must be developed and followed. In addition, water quality must be protected to ensure a sustainable resource.

- **Conservation**
  In the West Bank, considerable volumes of water are presently being lost through physical inefficiencies in the water infrastructure. Reduction of these physical losses is an important strategic principle to be achieved through implementation of conservation programs. A target reduction of physical losses to 20 percent of the gross water supply has been established by key stakeholders. This implies water management actions which include improved metering, leak detection, and network rehabilitation. The West Bank water management strategy recognizes that in this water-scarce environment, physical inefficiencies must be addressed through far-reaching conservation programs to maximize the net benefit of limited water resources.

- **Water Supply**
  Scarcity of water resources is perhaps the greatest problem facing the West Bank water sector. The West Bank water management strategy is quite clear in stating that supply should be provided to meet demand. As there is presently a gap between supply and demand in the West Bank, this strategic principle also implies action to either enhance supply and/or reduce demand. The strategy is not explicit with regard to how the gap between supply and demand should be filled. This allows for variability and flexibility in the management approaches considered by the IWRMP. Supply actions such as internal resource development and importation of external resources can be considered along with demand management actions.

- **Distribution**
  The strategy for water distribution is to improve accessibility to piped water for domestic users. A target of providing piped water to 100 percent of domestic users has been established by the water sector stakeholders. This target emphasizes the importance of developing water distribution; however, it may be difficult to achieve. According to World Bank data, 90 percent of the West Bank population presently has access to an improved water source. While not all of this is piped water (some is by tanker truck), this level of accessibility is comparable to the average (89 percent) for the Middle East and North Africa region. Water management action implications of this strategic principle include expansion of the West Bank distribution network in association with new supply development. The percentage of service connections can certainly be improved in the West Bank; however, the cost of achieving connections to 100 percent of the users may exceed users’ ability to pay.

- **Wastewater Management**
  The strategy for wastewater management has two objectives: 1) to protect the environment and the quality of water resources and 2) to develop a new resource in reclaimed wastewater. In general, the wastewater management strategy is to eliminate raw wastewater discharge to the natural environment through implementation of collection and treatment systems in urban West Bank areas and simpler treatment
technologies (i.e., septic systems) in rural areas. Where possible, wastewater will be reused for agricultural, industrial, or other non-potable use. This strategy proposes that wastewater be used to replace existing fresh water demand or to meet natural demand growth, as differentiated from creation of additional demand. This strategic principle implies construction of urban collection, treatment, distribution, and reuse systems, as well as rural septic treatment or other small-scale wastewater management technologies.

- **Financial Management**
  According to the strategic principles set forth by the water sector stakeholders, all actions taken in the water sector must be financially viable. In other words, projects for which costs exceed the ability to pay may not be considered. A target of full cost recovery for water sector projects has been set. Stakeholders recognize that in the short term it may only be possible to recover O&M costs; nevertheless, it is recognized that both capital and O&M recovery is required for long-term sustainability of an independent (non-donor reliant) water sector. This principle of financial viability implies development of a sound tariff structure and continued development of bulk and local service utilities.

- **Institutional, Administrative and Legislative Development**
  The West Bank water sector strategy calls for adequate institutional capability to manage resources and water-related infrastructure and to regulate water sector activities. This necessarily implies capacity building actions in the areas of water resources management and O&M, and development of service utilities. Specific administrative and legislative actions are also implicitly implied to support the regulation of the water sector by the sector institutions. Specific institutional, administrative, and legislative actions will vary according to the selected water management scenario.

**Water Management Axes**

The strategic principles elaborated in the IWRMP provide guidance for the development of various water management scenarios. In general, the strategies are clear and the range of management actions implied by the strategic principles is limited to a group of similar actions. Because the actions are based on sound technical principles, they are not expected to be particularly challenging in terms of internal political constraints on implementation and public acceptance. However, there is considerable flexibility in the approach which can be taken to meet the strategic principle to provide water supply adequate to meet demand.

Three distinct directions, or axes, of water supply development and demand management could apply in the West Bank:

- **Internal resources development** emphasizes the development of water resources internal to the West Bank (groundwater, surface water, and wastewater) to fill the water gap.
- **External resources development** emphasizes the development of water resources external to the West Bank (desalinated sea water or imported fresh water) to fill the water gap.
- **Demand management** emphasizes the reduction of demand (agricultural, municipal and industrial) to fill the water gap.

Any one of these approaches taken to the extreme yields a hypothetical solution for the management of West Bank supply and demand. These solutions each have consequences and risks in relation to the political complexity of implementation, potential for public acceptance, socio-economic and environmental consequences, technical feasibility, and potential costs. In addition to these extreme approaches to filling the water gap, an infinite number of solutions combine these basic strategies, and thus lie between the three axes.

This “surface” of potential solutions is shown on Figure 3.7. The points of intersection between the surface of solutions and the axes of development were used as the basis for developing water management scenarios to be analyzed with the goal of finding a preferred management solution that draws from all three axes. Each of the axes of water resources development and demand management is described in further detail below.

![Figure 3-8 Potential Solutions for the Management of Water Supply and Demand](image)

**Water Management Scenario Analysis**

To evaluate and compare the range of water management scenarios implied by the surface of solutions illustrated in Figure 3.7, the West Bank Water Management Analysis Tool (WBWMAT) was developed. The overall objective of the WBWMAT is to estimate the future water supply and demand on the West Bank as a result of various management actions aimed at either reducing demand or increasing supply, and to give the user a visual representation of these scenarios and the estimated cost associated with them. The WBWMAT develops projected demand curves from 2001 to 2025 based on baseline information and user input. Supply is represented graphically as bars or blocks along the demand curve in 5-year intervals from 2001 to 2025. The WBWMAT predicts the demand and supply of water resources to the West
Bank and the total and unit costs of the combinations of selected water management actions.

The WBWMAT consists of 28 worksheets. From the main menu the user can navigate to the different worksheets. The most important worksheet for the user is the Scenario Development worksheet. This worksheet allows the user to build scenarios and visually examine the affects of prescribed management actions on supply and demand. The demand and supply worksheets contain baseline data for each of eight administrative districts in the West Bank. In addition to these main worksheets, supporting worksheets are provided for the economic analysis portion of the tool. The interface also allows the user to change the baseline assumptions and goals and to see their effect on the supply and demand curves as well as on the total costs and unit costs of implementation.

One of the major goals of the WBWMAT is to provide screening level economic analysis of different scenarios. Fourteen actions which have a direct impact on water demand and supply and supporting conveyance and distribution were included in the economic analysis of the WBWMAT. Unit costs in $/m³ of new supply developed or demand reduced were developed for each of the relevant actions. The unit costs were divided into capital and O&M costs to provide a better understanding of actions that may appear relatively inexpensive to build, but may have a high O&M cost (or vice versa).

The WBWMAT was used to analyze each of the axes of water supply development and demand management illustrated in Figure 3.

**Internal Resources Scenario**

The internal resources axis of development focuses exclusively on the use of water resources internal to the West Bank to fill the gap between supply and demand. Internal resources within or adjacent to the West Bank boundaries include:

- Groundwater that can be developed from wells
- Surface water captured from ephemeral wadi flow
- Jordan River
- Harvested rainwater
- Fresh and brackish springs
- Wastewater resources

A development scenario emphasizing the use of internal resources to fill the gap between supply and demand would rely on significant additional groundwater development and access to Jordan River resources. Because groundwater resources are currently developed (by both Palestinians and Israelis) to near the sustainable limits and the lower Jordan River does not presently contain significant resources of good quality, implementation of an internal resources management plan to fill the gap between supply and demand relies on successful negotiation of Palestinian water rights to additional quantities in the Eastern, Northeastern, and Western groundwater basins and in the Jordan River. Additional supply quantities are available from wadi flow, rainwater harvesting, wastewater reuse and brackish water; however, the total volume of these resources that can be developed is not sufficient to meet the projected demand. Possible advantages and disadvantages of the internal resources axis of development are summarized in Table 3.1.
TABLE 3-1 Advantages and Disadvantages of the Internal Resources Axis of Supply Development

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Security of water supply</td>
<td>Reliance on water rights negotiation</td>
</tr>
<tr>
<td>High technical feasibility</td>
<td>Limited volumes immediately available</td>
</tr>
<tr>
<td>Autonomous management</td>
<td>Time required to implement may be great</td>
</tr>
<tr>
<td>Assertion of water rights</td>
<td>Finite limit to supply</td>
</tr>
</tbody>
</table>

Figure 3.8 shows an example of an internal resources scenario. As illustrated in the figure, sustainable limits of internal resources prevent full closure of the water gap by 2025.

External Resources Scenario

The external resources axis of development focuses on the use of water resources external to the West Bank to fill the gap between supply and demand. External resources may include:

- Desalinated Mediterranean Sea water (imported by pipeline)
- Desalinated Red Sea water (imported by pipeline or canal)
- Fresh water imported by pipeline
• Fresh water imported by tanker

While the volumes of water available through implementation of external resource development options are generally large, costs associated with specific importation options may be high. However, a scenario emphasizing external resources as the primary supply can significantly reduce the gap between supply and demand. It should be noted that as with the internal resources option, considerable political effort must be exerted to successfully develop resources along the external resource axis. Agreements for purchase of water may be necessary and right-of-ways for conveyance to the West Bank must be attained. Firm agreements with the supplying desalination plant or fresh water source provider must also be carefully negotiated to ensure reliability of the resource.

Possible advantages and disadvantages of the external resources axis of development are summarized in Table 3.2.

**TABLE 3-2 Advantages and Disadvantages of the External Resources Axis of Supply Development**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large volumes available</td>
<td>High cost of water</td>
</tr>
<tr>
<td>High quality source</td>
<td>Political complexity of necessary agreements</td>
</tr>
<tr>
<td>Not dependent on water rights</td>
<td>Technically complex (desalination)</td>
</tr>
<tr>
<td></td>
<td>High security risk</td>
</tr>
</tbody>
</table>

Figure 3.9 shows an example of an external resources scenario. As illustrated in the figure, development limits of external resources prevent full closure of the water gap by 2025.

**Demand Management Scenario**

The demand management axis of development focuses on reduction of projected West Bank water demand to reduce the gap between supply and demand. Demand management options may include:

- Restrictions on agricultural growth
- Restrictions on domestic demand
- Implementation of water-efficient crop patterns
- Implementation of water-efficient consumer use fixtures

Demand management emphasizes efficiency in water use and restriction of demand across the water sector over the development of additional supplies to meet projected demand. Generally, demand management schemes focus on reduction of demand in the agricultural sub-sector through sector growth restrictions and/or regulated water efficient crop patterns to allow for growth of the municipal demand. This appears to be a likely scenario for demand management in the West Bank where agricultural demand is presently approximately 70 percent of the total demand and domestic water
consumption is well below regional averages. Other methods to manage demand and reduce the water gap may include delaying achievement of target domestic demands and installation of water-saving consumer fixtures to reduce household demand. A feasible solution to significantly reduce the gap between supply and demand emphasizing demand management can be developed; however, the impact on the socio-economic framework of the West Bank may be great. Restriction of agricultural growth will have serious impact on the West Bank economy, which is presently agrarian, based. Even if subsidies and compensation are given to land-owners not to irrigate, the labor and markets associated with irrigated agriculture will be negatively impacted. Possible advantages and disadvantages of the axis of demand management are summarized in Table 3.3.

**TABLE 3-3 Advantages and Disadvantages of the Axis of Demand Management**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relatively inexpensive method</td>
<td>Potentially high socio-economic cost</td>
</tr>
<tr>
<td>Technically easy to implement</td>
<td>May require farmer subsidies for implementation</td>
</tr>
<tr>
<td>Not dependent on water rights</td>
<td>May be politically unfeasible</td>
</tr>
</tbody>
</table>

Figure 3.10 shows an example of a demand management scenario. As illustrated in the figure, limits of demand management prevent reduction of demand to the level of current supply.
Figure 3-9 West Bank External Resources Scenario

Figure 3-10 West Bank Demand Management Scenario
Conclusions

The goals, objectives, standards, policies and priorities of the Palestinian water sector that were identified and clarified as part of the IWRMP have provided the basis for a West Bank water management strategy developed around seven major principles of water resources management. These principles address: resource management; conservation; water supply and distribution; wastewater management; financial management; and institutional, administrative, and legislative development. Each of these principles implies specific actions which can be developed into short- and long-term scenarios for water resources development and management. For most principles, the implied actions or ranges of actions are relatively clear. With respect to water supply, three distinct directions or axes of development can be followed: internal resources development, external resources development, and demand management. Each of these axes can be followed independently to a solution that reduces the gap between supply and demand, but these independent solutions may have high political risks and socio-economic consequences. It is most likely that a “preferred” management solution exists that incorporates aspects of two or three of the development axes.

The West Bank Water Management Analysis Tool (WBWMAT) allows for flexible analysis of a range of scenarios without prejudice of assumptions made by demand estimators or resource evaluators. Analysis of water management scenarios representing the extreme points on each axis of development with the WBWMAT yielded the following specific conclusions.

1) Taken alone, none of the specific directions (axes) for water resources development in the West Bank will achieve closure of the water gap in 2025. A more likely solution will involve elements and actions associated with each axis.

2) Basic water supply and demand management activities including limited groundwater development, rainwater harvesting and water conservation can be implemented immediately irregardless of the long-range vision for water management.

3) Adoption of a long-range strategy for closing the gap between supply and demand will greatly depend on the formal quantification of water rights; however, even with maximum rights achieved, it is likely that both importation of external resources and demand management will be required to meet the goals and objectives of water sector development laid out by Palestinian stakeholders.

3.6 Evaluation of Water Resources Management Options in Palestine

3.6.1 Introduction

The framework is shown schematically in Figure 3-11. This note is concerned with the practicalities of developing the framework e.g.

- Who are the stakeholders, and how are they to be represented?
- What future scenarios are required, and what data are needed to specify them?
• What model simulations will be needed, and what information needs to be extracted from them?
• How are the alternative Management Options to be specified, and what data are required to do this?
• How are the Management Options to be evaluated, and how is the resulting information to be presented to the decision-makers?

**Figure 3-11 Frameworks for Assessing SUSMAQ Management Options**

### 3.6.2 Pressure-State-Response System

Increasingly, UN agencies and governments are adopting a Pressure-State-Response (PSR) framework for policy analysis (OECD, 1998). The PSR framework is based on the use of indicators which can measure the economic, social and environmental performance of a country, sector or system in terms of sustainability. The PSR framework has been adopted for use within the UN World Water Assessment...
Program (WWAP), and for evaluating alternative options for flood risk management in the UK.

The framework proposed for the evaluation of Management Options within SUSMAQ is closely aligned with the PSR framework. In the PSR context, three categories of indicator can be identified:

1. **Pressure Indicators**: These indicators focus on changes in the main drivers which create pressure on water resources. They can be physical (e.g., changes in climate resulting in reduced water availability), socio-economic (e.g., increasing demand for water for agriculture) or hydropolitical (e.g., allocations of water governed by politics).

2. **State Indicators**: These indicators focus on describing the state of the system in economic, environmental and social terms. An environmental indicator could measure the extent to which over-abstraction had depleted the resources of an aquifer; an economic indicator could be based on GNP/capita, while a social indicator could measure the link between poverty and access to water.

3. **Response Indicators**: These indicators measure the actions taken to improve the state of the system, and the resulting impacts. The emphasis here is on identifying responses which can lead to more sustainable futures, measured in economic, social and environmental terms. In SUSMAQ terms, the responses are the Management Options.

Provision is made for iteration and feedback within the PSR framework. For example, if the responses do not lead to more sustainable system performance, then alternative responses need to be considered, and the system state re-evaluated. Similarly, the socio-economic pressures might need to be altered e.g. by reducing the amount of water allocated to agriculture. However, this could lead to increased imports of food (Virtual Water) with a loss of self-sufficiency and a negative impact on foreign exchange. The PSR framework, with feedbacks, is shown in Figure 2.

![Figure 3-12 the Pressure-State-Response (PSR) System With feedbacks.](image-url)
Before proceeding to discuss the definition of indicators, it is necessary to consider what the overall objectives of water resources management in Palestine are. Economic, social and environmental objectives can be defined, but there will inevitably be conflicts between these objectives. For example, self-sufficiency in food production may result in an opportunity loss in economic returns elsewhere. Similarly, industrial expansion undertaken over aquifer outcrops can contribute to economic growth but may lead to aquifer pollution, resulting in potential health problems and longer term water quality degradation unless investments are made in water treatment facilities. Over-abstraction to support the expansion of industry or irrigated agriculture may lead to springs in rural villages drying up, with consequent impacts on livelihoods.

To arrive at a preferred Management Option, it will be necessary to establish tradeoffs between the economic, environmental and social objectives. These tradeoffs can be expressed within the Multicriteria Decision Analysis (MCDA) framework discussed below (Section 3.6), and the outcomes of different societal preferences expressed in economic, social and environmental sustainability terms. However, the choice of the preferred option rests with a decision-maker or a group of stakeholders representing the various interests affected by water resources management outcomes.

### 3.6.3 Describing Pressures on Palestinian Water Resources

#### 3.6.3.1 Climatic Scenarios

Climatic variability and change can clearly create pressure on water resource systems through droughts of varying severity. In the PSR framework, climatic scenarios will be generated corresponding to (a) historic climatic conditions and (b) future climatic conditions. These scenarios will be expressed as spatio-temporal series of rainfall and temperature, with a spatial grid resolution of 5km, and a temporal resolution of one day. In the case of the historic climate, the period chosen for analysis will be 1986-98. The stochastic space-time rainfall model will be used to generate two types of series: (i) alternate space-time realizations of rainfall and temperature over the West Bank and Gaza which reproduce exactly the historical point series (conditional simulations) and (ii) alternative space-time realizations of rainfall which could be observed (a) under the current climate and (b) under the predicted future climate.

These simulated rainfall and temperature time series can be regarded as climatic indicators. Droughts are a consequence of natural climatic variability, and it is through such events that climate can stress the West Bank and Gaza aquifers. Attempts have been made to define drought indicators (e.g. the Palmer Drought Severity Index) which can help in defining the onset of a drought. However, it is not clear what use could be made of such an indicator in the SUSMAQ project, since the full rainfall and temperature series will be used in the simulations.

**Question:**

How many realizations of rainfall and temperature are needed, and over what historic and future periods?
3.6.3.2 Hydropolitical Scenarios

The West Bank aquifers are shared between Palestine and Israel, but under the current enforced allocation system, the sharing is inequitable. Depending on how the Final Status Negotiations develop, various future scenarios can be contemplated, as well as the current situation:

1. The Israelis and the Palestinians continue with the same current abstraction patterns (status quo).

2. Under International Law, the Palestinians are entitled to an equitable utilization of the sustainable yield of the shared resources, and could abstract more water e.g. 30%, 100% and 90% of the sustainable yields of the Western, Eastern and North Eastern Aquifer Basins, respectively.

3. Under Camp David II, the Palestinians could increase their abstractions by 50 MCM/yr from the Western Aquifer Basin, 80 MCM/yr from the Eastern Aquifer Basin, 10 MCM/yr from the North Eastern Aquifer Basin, and 40 MCM/yr from the Jordan River.

4. Israeli agriculture abstractions are reduced by 30%.

An indicator which measures the degree of inequitable utilization of the shared water resources could be defined for use in the MCDA framework (e.g. the ratio of Palestinian to Israeli per capita consumption).

The above scenarios would be implemented when simulating the Palestinian abstractions from the aquifer over time. The definition of the sustainable yield of the aquifers is considered under Section 5 below.

3.6.3.3 Socio-Economic Scenarios

Socio-economic scenarios are expressed in terms of water demands from the different sectors (domestic, commercial, industrial, agricultural). Demand scenarios are typically expressed as single figure yearly values, projected over a planning horizon, and broken down by sector. However, it is recognized that such projections are highly uncertain, since the internal and external economic and social forces which can affect demand in the future are difficult to anticipate. Sensitivity analysis based on projections above and below the best estimate have been carried out in the past, but these tend to be rather arbitrary.

Recently, an attempt has been made in the UK to define a set of possible global and environmental future scenarios which would influence sectoral activity (DTI, 1999). The scenarios use two core dimensions of social change: social values and systems of governance. These dimensions are used as axes to define four scenarios which describe the UK during the period 2010 – 2040 (Figure 3.13).
Social values – on the horizontal axis, these reflect policy-making priorities, political preferences and patterns of economic development. At one end of the spectrum social values are dominated by consumerist attitudes which emphasise individualism, materialism and private consumption. Concern for the environment focuses on specific problems that impact on the individual or their immediate local area. In contrast, community-oriented values are concerned with securing long-term social goals such as equity and sustainable economic development. There is a strong emphasis on the enhancement of collective goods and services, reflected in the high priority placed on the use of resources and environmental problems.

System of governance – the vertical axis represents the structure of political authority and decision-making. Globalisation is characterised by the redistribution of political power and influence away from the nation state towards pan-European and global institutions such as the United Nations (UN) and World Trade Organisation (WTO). Economic activity is locked into international trading systems, dominated by trans-national corporations. This is distinct from regionalisation, where national sovereignty is strengthened and there is a movement towards regional devolution and local government.

In broad terms the four scenarios can be characterized as:

Provincial Enterprise Scenario: a future in which the nation state disengages from international political and economic systems of governance. This is a low growth, low wage and low investment scenario with little concern for social equity. The environment is perceived as a low priority issue despite the increased pressures placed on natural resources.

World Markets Scenario: a future in which a highly developed and integrated world trading system generates high levels of economic growth. Although personal affluence rises, there is little concern for social equity.
Awareness and concern for the environment is low, particularly among the less well off.

**Global Sustainability Scenario:** A future where global institution plays a central role resolving social and environmental problems. High levels of investment in research and development result in the development of innovative clean technologies that benefit the environment.

**Local Stewardship Scenario:** A future dominated by regional and local systems of government. Working at the local level, environmental problems are resolved through collective action.

In the context of water resources, the UK Environmental Futures framework provides a high level assessment of water demand as increasing, decreasing or stabilizing, and broad qualitative indicators of the levels of leakage, water use and water efficiency. The UK Environment Agency has used these four Futures to generate four corresponding demand scenarios for the period 2010 – 2040 (Environment Agency, 2001a). These are not intended to be predictions of the future; rather they provide an indication of alternative patterns of social development governing water demand and attitude towards the environment against which different water resources management strategies can be tested (Environment Agency, 2001b).

Clearly, the Environmental Futures derived for the UK will not apply to Palestine, but there are nonetheless some points which can be made about the generation of Socio-Economic and Water Demand Scenarios in the present context:

(i) Globalization and other external developments in the world economy and trade will influence the development of the Palestinian economy in the future, and agreements reached (or not reached) between the developing and developed countries over subsidies etc. will affect Palestinian trading opportunities;

(ii) The way in which the Israeli economy develops in response to globalization and other forces will affect trading and economic opportunities with Palestine which will in turn affect demand for the shared water resources;

(iii) The robustness of Management Options needs to be tested against a number of possible future alternative scenarios of water demand, not just one, and the economic, social and environmental assumptions underlying alternative demand scenarios need to be properly defined.

**3.6.3.4 SUSMAQ Scenarios**

In formulating Socio-Economic and Hydro-political scenarios, and the responses to them (Management Options), it has been proposed that they should be categorized under three headings.
1. **Current State**

**Socio-economic Scenario:** substantially subsistence and internal market economic development – humanitarian projects.

**Hydro-political Scenario:**
- based on Oslo II allocations with testing of impacts of reduced quantities (Mekorot reductions)
- Separation wall.

2. **Consolidating State**

**Socio-economic Scenario:** still significant reliance on agriculture but initiation of more internal regional trading and industrial development, particularly agro-economic industries initially.

**Hydro-political Scenario:**
- Equitable share of aquifer resources

3. **Long-term Development**

**Socio-economic Scenario:** changing development economic pattern from agriculture to industry – agro/service/skilled/tourism and international trading developing.

**Hydro-political Scenario:**
- Equitable share of aquifer resources
- Abstraction from Jordan.

### 3.6.4 Describing the State of Palestinian Water Resources

The past history of abstraction from and pollution of the shared Israeli and Palestinian water resources has conditioned the overall current environmental state of these resources. There is evidence of over-abstraction in some areas of the West Bank aquifers, and the Gaza aquifer and Jordan River are seriously degraded relative to their original states. There is a need to define a baseline reference state for each of the resources which represents sustainable long-term utilization, and to measure departures from this reference state at the beginning and end of the periods over which demand scenarios are imposed on the aquifers. If the aquifer state degrades through over-abstraction over the scenario period, then the abstraction regime is not sustainable. Appropriate responses (Management Options) must then be defined to achieve sustainable abstraction regimes (the Response element of the PSR framework). It should be noted that the abstraction regime will reflect the set of structural and non-structural measures employed to match supply and demand (Management Options), as well as the pressures exerted by the socio-economic (demand) scenario. In this regard, structural measures include wells/well fields, water transfers, desalination, while non-structural measures include virtual water, regulation (environmental and economic) etc.
Indicators needed to define the states of the aquifers, and departures from the reference states, could include:

1. The proportion of the aquifer where the drawdown is more than 30% of the saturated thickness;
2. The proportion of the aquifer where abstraction is more than 90% of sustainable yield;
3. The proportion of the aquifer where salinity levels exceed a specified threshold due to over-abstraction;
4. The proportion of the aquifer where nitrate levels are higher than the recommended WHO level;
5. The proportion of the aquifer where faecal organisms are present etc.

To define sustainable yield it is proposed to use a 10 year moving average of annual recharge, and to limit abstraction to less than 90% of this value. However, during a multi-year drought, it may be necessary to relax this restriction. An overall measure of aquifer state from a water quantity perspective could be based on the total amount of over-abstraction relative to the total amount of recharge over a scenario period.

It will also be necessary to consider the spatial juxtaposition of areas where aquifer degradation is occurring, and demand centers (towns, villages). This will have implications for the Response needed to address these problems. Using a GIS, indicators could be defined which capture the degree of spatial congruence between aquifer degradation and demand areas.

Social and Economic states can be defined consequent on the environmental states. For example, over abstraction can lead to springs drying up, particularly during drought periods with impacts on livelihoods. Proxy social indicators could be:

(i) The proportion of village springs that have dried up over the scenario period.
(ii) The proportion of sampled springs where water quality constitutes a health risk.

The economic indicators linked to the state of water resources could be based on agricultural production which is dependent on irrigation from shallow wells, and loss in productivity associated with aquifer degradation. This could also be mapped spatially, and when combined with other measures of economic productivity, could be expressed and mapped as increase/decrease in GNP/capita over the scenario period.

**Question:**

How can indicators of the economic and social states conditioned by water resources be defined?
3.6.5 Measuring Responses to Management Options

3.6.5.1 Indicators of Environmental Sustainability

Given climatic, hydropolitical and socio-economic scenarios, indicators are needed to measure the performance of different Management Options for Palestinian water resources. The emphasis here is (a) measuring how well the aquifers perform in meeting the demand regime imposed on them (e.g. how should abstraction be distributed in space over the aquifer), and (b) what is the impact of the abstraction regime on the state of the aquifer (Section 4 above). Recently, Fowler et al (2003) have applied a set of sustainability indicators to model the impacts of climate change and variability on the reliability, resilience and vulnerability (RRV) of a (surface) water resource system. Reliability is defined as the proportion of the time over which the demand can be met; resilience gives an indication of the speed of recovery of the system from a failure, and vulnerability is a measure of the extent of failure. It is proposed to apply these indicators to measure the performance of the West Bank and Gaza aquifers under alternative management options. The combined use of these indicators is known as RRV analysis.

![Figure 3-14 Definition of Satisfactory(S) and Unsatisfactory (U) states](image)

Suppose that the water level in an aquifer fluctuates over time as shown in Figure 3. If the water level is above a certain critical level $C$, the aquifer is in a satisfactory state, while if the water level drops beneath the critical level, the aquifer is in an unsatisfactory state (U). And the abstraction cannot be met. Reliability is then defined as the proportion of the total period $T$ that the aquifer is in the unsatisfactory state.

Resilience is based on the number of transitions from the state U to the state S over the period $T$. The examples presented in Figure 3-15 illustrate the resilience concept. Both systems A and B spend the same amount of time in the unsatisfactory state U and so the reliability is the same for both. However system A recovers much more quickly than system B, and so System A has a higher resilience value than system B, and can recover more quickly from failure. This is a particularly important measure for an aquifer, since in some cases; recovery can take years if over-abstraction occurs.
The third indicator, **Vulnerability**, is defined as follows. Firstly, the periods of failure are defined as in Figure 3-14, and the shortfall (difference between total demand over the failure period, and the amount of water delivered) is defined for each failure period.

Vulnerability is then defined as the ratio of the maximum shortfall in a failure period to the total demand over the period. It measures the impact which the failure has in failing to meet demand.

Mathematical definitions of Reliability (\(C_R\)), Resilience (\(C_{RS}\)) and Vulnerability (\(C_V\)) are provided in Annex A.

The ASCE Task Committee on Sustainability Criteria (1996) has suggested that \(C_R\), \(C_{RS}\) and \(C_V^S\) could be combined to provide a single sustainability indicator:

\[
C_{SUS} = C_R \cdot C_{RS} \cdot (1 - C_V)
\]
which lies in the range $0 \leq C_{\text{SUS}} \leq 1$. Higher values of $C_{\text{SUS}}$ indicate that the performance of the system in meeting demand is more sustainable. However, the impact on the system state itself (the aquifer) also needs to be considered in making a sustainability assessment. As discussed in Section 3.6.4 above.

It should be noted that the definition of vulnerability employed here does not accord with the more traditional use of the term vulnerability used in relation to aquifer pollution. Moreover, vulnerability also has a different meaning in a social context.

In addition to computing the above water quantity-based measures of performance, similar measures could be applied based on the definition of a critical condition C for water quality (e.g. salinity). Moreover, economic and social measures of sustainability also need to be defined which capture

(a) The economic impact of failures e.g. shortfalls in industrial and/or agricultural production;

(b) The social impact of failures e.g. impacts on livelihoods when springs dry up over extended periods.

The above sustainability indicators can be applied locally, or to a whole aquifer. Feedback obtained from mapping these indicators may help in re-defining abstraction zones to achieve more sustainable aquifer performance.

3.6.5.2 NWP Indicators

The following are the indicators used in the National Water Plan (NWP) for ranking of systems within the same sub-sector in order to project an implementation program on a project by project basis over a 20 year horizon. The system contains 6 sub-sectors – water supply, wastewater, water conservation, storm water, water resources and agriculture to form a comprehensive investment plan for the entire sector. The indicators are specifically set up for water supply systems but can be adapted to the other sub-sectors. The implementation program includes investment cost, operation and maintenance cost and manpower implications and the system can monitor the improvements in quantity, quality and reliability achieved over the program period. Cost recovery and the balance of investment between sub-sectors and regions can also be analyzed as can the impacts of any amendments to the program. The statistics can be analyzed at national and regional down to Governorate level at present. The system does not contain any overall assessment of optimal sustainability and has limited socio-economic criteria as indicated. Neither does the system allow for comparison between different developments scenarios.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Measured</th>
<th>Priority rating</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water quantity</td>
<td>Percentage of existing Consumption below target</td>
<td>3 to 1</td>
<td>100%</td>
</tr>
</tbody>
</table>
Question:
What economic and social indicators of sustainability are to be employed?

3.6.6 Multi-criteria Assessment of Management Options

3.6.6.1 UNESCO MCDA Method and Case Study

In developing a sustainable water resources management plan for a country or region, economic, social and environmental objectives need to be considered, since the plan must be sustainable from each of these standpoints. However a conflict arises if socio-economic development is to be prioritized at the cost of degradation in environmental quality. Essentially, an acceptable balance between these two conflicting objectives must be established which reflects the overall preference of a society. To support the decision-making process in arriving at such a balanced position, Multicriteria Decision analysis (MCDA) techniques have been developed which enable different preferences to be expressed through the MCDA process. Different preferences can be reconciled by establishing trade-offs between the conflicting objectives. This process is depicted graphically in Figure 3-16.
Figure 3-16 Tradeoffs between environmental and economic objectives

Suppose a decision maker (DM) has to choose between Options A and B. If the DM is willing to choose Option B rather than A, then the DM is willing to forego $\Delta ER$ to prevent a decrease in environmental quality $\Delta EQ$. Tradeoffs reflect the preferences of the decision-maker. A key question to be posed at this juncture is: who is the decision-maker? In the case where the sustainable management of a nation’s water resources is concerned, there are many sectors of society (domestic users, farmers, industrialists, environmentalists) whose positions need to be represented in the decision-making process. Increasingly, participatory approaches to decision-making are being pursued through which different preferences can be expressed. An MCDA procedure can help in expressing these different preferences, and in arriving at a compromise solution which is acceptable to the different parties. There are several MCDA techniques documented in the literature, with varying levels of mathematical complexity and transparency. The latter aspect is very important; the assumptions underlying the chosen MCDA technique should be clear, and it should be transparent how the trade-offs are expressed, and the final ranking(s) of Management Options arrived at.

UNESCO (1987, 1988) carried out an extensive study in which an MCDA technique (Composite Programming) was applied to the integrated environmental evaluation of water resources development projects. They produced a manual (1988) for the application of the technique, and applied it in several case studies. It is proposed to employ this technique for the evaluation of Management Options in SUSMAQ.

The starting point with the UNESCO MCDA method is a set of Basic Indicators which must be defined so as to describe comprehensively the economic, social and environmental performance of a set of projects (Management Options for SUSMAQ). Guidance is given in the UNESCO publications (1987, 1988) on the definition and selection of appropriate indicators. However, it is the responsibility of the analyst to
ensure that the set of indicators chosen is appropriate for the socio-economic/environmental system in question. In Sections 4 and 5, various indicators were discussed which might be used to describe the state of the Palestinian Water resource system, and the performance of various Management Options. Definition of the final set of indicators to be used, and the set of Management Options to be evaluated, will be a major focus for forthcoming SUSMAQ Workshops.

The application of the UNESCO methodology will be illustrated here through a case study involving the preparation of Master Plan for a developing country region which is referred to as the Demovale Lakes Basin (the case study is real, but the region must remain anonymous). For the case study, a set of 10 possible projects (Management Options) needed to be ranked to prioritize investment under the Master Plan:

1. Agricultural Inputs Supply and Distribution
2. Strengthening Agricultural Extension Services
3. Coffee Processing Study
4. Cotton Production Development
5. Review and Reappraisal Studies for Medium and Large Scale Irrigation Development Projects
6. Phase 2 EEC Inland Fisheries Resource Development Project
7. Medium/Long-Term International Wildlife Tourism
8. Re-evaluation of the Viability of the Enlarged Soda Ash Project
9. Town T Geothermal resources Utilization Project
10. Rural Water Supplies Improvement Program

To describe the set of 10 Management Options (MOs), a set of 13 Basic Indicators was defined as follows:

1. Economic Sustainability
2. Contribution to Foreign Exchange
3. Revenue Generation
4. Contribution to Priority List
5. Increases in Jobs
6. Increase in Farmer Income
7. Increase in Non Farmer Income
8. Project Output
9. Change in Water Quantity
10. Change in Land Quantity
11. Change in Water Quality
12. Change in Land Quality
13. Effects on Wildlife and Vegetation

For each MO, prior studies had been carried out to determine values for the indicators. In some cases, the values would be based on modeling studies, economic analyses, environmental impact assessments etc, while in other cases; a value might have to be assigned to the indicator based on experience/subjective judgment. It is desirable to keep this type of indicator evaluation to a minimum; the indicators must, as far as possible, be data-based.
Table 3-4 presents the values for the various indicators for the set of MOs. Based on the available information, scales from 'bad to good', 'negative to positive' etc. were defined for each indicator, and a value was then assigned for each MO.

Table 3-4: Basic indicator values for the ten projects.

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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

For example, in the case of the Indicator ‘Increase in Jobs’, the scale used was

<table>
<thead>
<tr>
<th>Losses</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>insignificant</td>
<td>Losses</td>
<td>insignificant</td>
<td>low</td>
<td>moderate</td>
<td>major</td>
<td>high</td>
</tr>
</tbody>
</table>

(Note: it is not necessary to do this if quantitative estimates are available; the Basic Indicators can use the original data).

Given the table of Basic Indicators, the first step is to standardize all indicators on to the range 0-1. This is done using the range of the values which is (0-5) for the example given above; alternatively, best and worst values could be defined independently of the data. The standardization procedure is described in Annex 2.

The next step in the UNESCO MCDA method is to group the Basic Indicators into a number of Second Level Groups. Headings for these groups need to be defined; for the Demovale Case Study, these were:

- Economic
- Social
- Ecology
- Natural Resources
The assignment of the Basic Indicators to these groups is shown in Table 3-5. For each group, a set of weights is defined which must sum to 1; they are assigned on the basis of the perceived relative importance of the different Basic Indicators. Also shown in Table 3-5 are 'Balancing Factors'; these are assigned to try to ensure that certain critical indicators do not depart too far from their optimum values when the MOs are being evaluated using the MCDA method (e.g. in the case of water quality).

Table 3-5: Indicators and Weights assigned for Second Level Groups

<table>
<thead>
<tr>
<th>Second Level Group</th>
<th>Indicator</th>
<th>Weight</th>
<th>Balancing Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td>Economic sustainability</td>
<td>0.3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Contribution to foreign exchange</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Revenue generation</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contribution to priority list</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Social</td>
<td>Increase in jobs</td>
<td>0.4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Increase in farmer income</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increase in non-farmer income</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Project output</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Ecology</td>
<td>Change in water quality</td>
<td>0.4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Change in land quality</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Change in wildlife and vegetation</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Natural Resources</td>
<td>Change in water quantity</td>
<td>0.6</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Change in land quantity</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

Using the weights and balancing factors, composite indicators are then calculated for each MO by applying the weights and balancing factors shown in Table 3-5; this leads to four second level composite indicators corresponding to the headings defined above. Weights are then assigned to these second level indicators (typical values are shown in Table 3-6) and two third level composite indicators are then calculated which measure the overall Socio-Economic and Environmental performances of the different MOs.

Table 3-6: Composite indicators and weights for Third Level Groups

<table>
<thead>
<tr>
<th>Third Level Group</th>
<th>Index</th>
<th>Weight</th>
<th>Balancing Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socio-Economic</td>
<td>Economic</td>
<td>0.7</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Social</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Environmental</td>
<td>Ecology</td>
<td>0.6</td>
<td>2</td>
</tr>
<tr>
<td>Quality</td>
<td>Natural Resources</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

Finally, these two composite indicators are weighted to reflect the overall balance between socio-economic development and environmental quality (Table 3-7), resulting in a single composite indicator which measures the overall performance of each MO. For the weights shown in the above tables, the final ranking of the MOs is shown in Table 3-8. A graphical representation of a ranked set of Management Options is shown in Figure 3-17.
Table 3-7: Corporate indicators and weights for overall evaluation

<table>
<thead>
<tr>
<th>Index</th>
<th>Weight</th>
<th>Balancing Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socio-Economic</td>
<td>0.65</td>
<td>1</td>
</tr>
<tr>
<td>Environmental Quality</td>
<td>0.35</td>
<td></td>
</tr>
</tbody>
</table>

Table 3-8: Final Ranking of Management Options

<table>
<thead>
<tr>
<th>Rank</th>
<th>Project</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>0.766</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0.586</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>0.554</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>0.520</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>0.464</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>0.446</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>0.446</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>0.435</td>
</tr>
<tr>
<td>9</td>
<td>10</td>
<td>0.433</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>0.409</td>
</tr>
</tbody>
</table>

Figure 3-17: Graphical representation of a set of ranked Management Options
The ranking obtained reflects the preferences expressed through the weights assigned in the various stages of the MCDA evaluation. Different weights will lead to different rankings. In this respect, it is desirable not to choose MOs which are too sensitive to variations in the weights i.e. they are not robust. A sensitivity analysis should be performed to identify such non-robust options.

Different stakeholder groups with different preferences can be expected to assign different weights, and possibly to emerge with different rankings. If the best MO does not change under such circumstances, then that is clearly the preferred MO. However, in the more likely event that the ranking changes, then some form of compromise must be reached and expressed through a set of weights that gives a final ranking which is acceptable to all.

In utilizing this MCDA method, the underlying assumptions and limitations of the method must be borne in mind. Firstly, as already noted, there are always conflicting opinions about what is best for society, and it is virtually impossible to determine objectively what is best. What the MCDA method can do is to quantify these different preferences, and therefore provide support for the decision-making process needed to arrive at the 'best' MO, or set of MOs.

6.2 SUSMAQ Management Options

Management Options which have been suggested for evaluation in SUSMAQ are categorized under the three headings used for the Hydro-political and Socio-economic scenarios:

1. **Current State**
   - Maximization of aquifer abstraction
   - Optimize operation within limits of existing agreements (response to reduction in Mekorot supplies?)
   - Rainwater harvesting/tanker supplies
   - Protection of present livelihoods (basic water supply of satisfactory quality and reliability)
   - Response to separation wall

2. **Consolidating State**
   - Increase in domestic/municipal supply towards WHO levels
   - Response to Agro/Industrial needs
   - Re-use of wastewater

3. **Long-term Development**
   - Additional internal (surface water?) and external supplies
   - Alternative agriculture/industry/virtual water supply-demand gap options
Some of the MOs proposed under 'Current State' come essentially under day-to-day PWA operations which fall outside the scope of SUSMAQ where the focus is on strategic development. However, the SUSMAQ Decision Support Tool (Section 7) should be adapted to deal with the evaluation of Current State MOs where this can draw on the models and results produced in SUSMAQ.

3.6.7 **A Decision Support Tool (DST) for the Evaluation of SUSMAQ Management Options**

The case study described in Section 6 illustrates how the UNESCO MCDA method could be applied in SUSMAQ. In Sections 4 and 5, some possible indicators for use within SUSMAQ have been defined. These and other indicators will be considered in the forthcoming SUSMAQ Workshop in Cyprus, together with an appropriate set of Management Options. Hydrological/hydrogeological and water quality data, model simulations, surveys related to sustainable livelihoods, costing/economic evaluations for various developments etc will provide the information from which the basic indicators can be defined.

The MCDA method has been reprogrammed using Visual Basic/Excel, and tested against a previous DOS version of the MCDA software provided by UNESCO. This will provide a flexible environment for the further development of the Decision Support Tool (DST), and its possible interfacing with the CH2MHILL spreadsheet tool for the costing of different alternatives for matching supply and demand etc. The resulting DST will perform the following roles:

(i) Integrate the technical 'engine' of SUSMAQ, which incorporates climate/rainfall modeling, recharge modeling, groundwater flow and contaminant transport modeling, with the socio-economic 'engine' which includes the costing and economic evaluation of development projects, quantification of poverty alleviation/contribution to sustainable livelihoods etc.;

(ii) Facilitate economic, social and environmental sustainability assessments which are sensitive to the spatial and temporal variability in water availability and demand;

(iii) Allow the Pressure State – Response (PSR) approach to sustainable development to be implemented for Palestinian water resources;

(iv) Allow 'What if – what if not' hypotheses about the future, expressed through climatic/hydropolitical/socio-economic scenarios, and/or different Management Options, to be evaluated using economical, social and environmental sustainability criteria;

(v) Allow economic, social and environmental objectives to be balanced in a sustainable way in the management of Palestinian water resources;

(vi) Allow the PWA to continually evolve and evaluate Management Options which respond to evolving climatic, socio-economic and hydropolitical scenarios

41
References


Annex 1: Definition of Reliability, Resilience and Vulnerability (RRV) Indicators

The water level in an aquifer is described by a variable $X_t$. Define a critical level $C$ (which can vary over time) such that when the water level is above the critical level, the aquifer is in a satisfactory state ($S$) while, if the water level drops beneath the critical level, the aquifer is in an unsatisfactory state ($U$) and the abstraction cannot be met. An indicator $Z_t$ is defined as

$$Z_t = 1 \text{ when } X_t \geq C$$
$$Z_t = 0 \text{ when } X_t < C$$

Reliability is then defined as the proportion of the time that the aquifer is in the unsatisfactory state:

$$C_R = \frac{\sum_{C=1}^{T} Z_t}{T}$$

(1)

where $T$ is the total number of time intervals considered.

Resilience is based on the number of transitions from the state $U$ to the state $S$ over the period $T$. Here an indicator $W_t$ is defined such that

$$W_t = \begin{cases} 1 & \text{if } X_t \leq C \text{ and } X_{t+1} > C \\ 0 & \text{otherwise} \end{cases}$$

i.e. $W_t = 1$ if a transition occurs from the unsatisfactory state $U$ to the satisfactory state $S$. A resilience indicator is then defined as

$$C_{RS} = \frac{\sum_{t=1}^{T} W_t}{T - \sum_{t=1}^{T} Z_t}$$

(2)

where the denominator in equation (2) measures the amount of time spent in the unsatisfactory state $U$. 
The third indicator vulnerability, is defined as follows. Firstly, the periods of failure are defined, and the shortfall (difference between total demand over the failure period, and the amount of water delivered) is defined for each period. If the shortfalls are defined as $M_1$, $M_2$, $M_3$, ..., corresponding to failure periods 1, 2, 3, ..., then a standardized measure of vulnerability may be defined as

$$C_v = \frac{\max \{M_1, M_2, M_3, \ldots \}}{\sum D_i}$$

(3)
Annex 2: Technical Details of the UNESCO MCDA Method

1. Select basic indicators $Z_i$ to represent the state of the system being analysed: a hierarchy of 4 levels is used typically:

   Level 1: Basic Indicators
   Level 2-4: Composite indicators

2. Standardize the basic indicators to the range 0-1

   $$S_i = \frac{Z_i^+ - Z_i}{Z_i^+ - Z_i^-}$$

   where $Z_i^+$ is the best value and $Z_i^-$ is the worst value.

   $S_i$ is a measure of acceptability of the value of $Z_i$ e.g. if $Z_i = 6.8$, $Z_i^+ = 13.8$, $Z_i^- = 2.2$, then $S_i = 0.60$.

   **Note:** $S_i = 0$ corresponds to the best value, and $S_i = 1$ corresponds to the worst value.

3. Calculate second level composite distances

   $$L_j = \left[ \sum_{i=1}^{n_j} \alpha_{i,j} S_{ij}^p \right]^{1/p_j}$$

   where

   $S_{ij} = indicator \ i \ in \ group \ j$;
   $\alpha_{ij} = weight \ applied \ to \ the \ ith \ indicated \ in \ grouping$;
   $n_j = number \ of \ indicators \ in \ group \ j$;
   $p_j = balancing \ factor$

   As $p_j \rightarrow \infty$, $L_j \rightarrow \max(S_{ij})$; normally $p=1$ or 2.

   If nutrient is a limiting factor (e.g. phosphorus controlling eutrophication) then $p \geq 3$.

   Composite Indicators are defined as

   $$C_j = 1 - L_j$$

   where the best value of $C_j$ is 1 and the worst value is zero.
$L_j$ therefore represents a measure of the distance from the ideal point, for which $L_j = 0$.

4 Calculate 2 third level composite distances:

$$L_k = \left[ \sum_{j=1}^{m_k} \alpha_{jk} L_{jk}^{p_k} \right]^{1/p_k}$$

(3)

$k = 1 : \text{EQ (Environmental Quality)}$

$k = 2 : \text{SE (Socio-economic)}$

$m_k : \text{Number of elements in each third level group.}$

5. Calculate a final overall Composite Distance

$$L = \left[ \alpha_1 L_1^2 + \alpha_2 L_2^2 \right]^{1/2}$$

(4)

and a final Composite Indicator

$$C = 1 - L$$

6. The alternative Management Options are then ranked based on their $C$-values, with $C = 1$ represents the ideal point. The $L$-values represent the distances from the ideal point and can be shown on a graphical plot (Figure A1). Zones for Good, Acceptable and Poor MOs can be defined using the following expression for the boundary curves.

$$\beta = \left[ \alpha_1 (1 - x)^p + \alpha_2 (1 - y)^p \right]^{1/p}$$

(5)

where

$(x, y) = \text{point on curve.}$
Questions from Past Papers

Input Data for Question 1 & Question 2:

You are involved in a water resource management and development strategy for the Faria Catchment as shown below. **The water resources management strategy requires that the sustainable yield of aquifers and wadi runoff volumes must be well understood and that the aquifer management plans should define specific well abstraction scenarios to be followed. These scenarios should allow the exploitation of brackish water in some shallow aquifers in the project area.**

Al Faria Catchment Water Resources:

- Wells: 12.85 Mcm/yr.
- Springs: 16.1 Mcm/yr.
Al Faria Agriculture Data:

Cultivated land   125,000 dunums.  
( assume 75 % is suitable for irrigation)  
Water requirement 600 m³/yr per dunum.

Demographic Data:

Population at planning horizon = 30,000.
Per Capita consumption  = 150 l/day.
Losses  = 30 %.

Q # 1: Water Resources Management strategies and actions

You are asked to look at the following water resource management aspects in the Catchment:

Conservation Measures (demand management measures)  
Water supply and Distribution  
Wastewater Management  
Financial Management  
Institutional, Administrative and Legislative Development

State what are the management strategies and actions as indicated below (use the allocated space only):

1. (a) Management strategy of Conservation Measures
   
   (b) Actions
      
      i - 
      ii - 
      iii - 

2. (a) Management strategy of Water supply and

   i - 
   (b) Actions
      
      i - 
      ii - 
      iii -
3. (a) Management strategy of Wastewater Management
   
   i -
   ii -

   (b) Actions
   i -
   ii -
   iii -

4. (a) Management strategy of Financial Management
   
   i -

5. (a) Management strategy of Institutional, Administrative and Legislative Development
   
   i -

   (b) Actions
   i -
   ii -
Q#2: Water Resources management options?

(a) Estimate total available water in Mcm/yr in the Faria Catchment?

(b) Estimate the water needs for domestic and irrigation/agricultural purposes?

(c) Determine the gap between available water and water needs?

(d) How can you bridge the gap between water supply and water needs (suggest five relevant solutions only).

1.
2.
3.
4.
5.

(e) In the processes of assessment of the above 5 solutions, develop 3 environmental and 2 socio-economic Indicators:

   i- 3 Environmental Indicators

   ii- 2 Socio-Economic Indicators

(f) What do you understand about the term Pressure-State-Response System for assessing the 5 solutions in (e) above?
Q #3: Environmental Sustainability Indicators

The sustainable yield of the Western Aquifer Basin of Palestine is decided in Oslo II agreement as 362 Mcm/yr which is estimated to meet the demand of people using this basin. This critical limit shown on the figure below which also shows the total annual recharge to this basin from 1964 till 1998.

<table>
<thead>
<tr>
<th>Period of Failure ($\Delta T$)</th>
<th>Recharge over ($\Delta T$) Mcm</th>
<th>Abstraction of ($\Delta T$) Mcm</th>
<th>Shortfall Mcm</th>
<th>Cv</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>577</td>
<td>936</td>
<td>359</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>677</td>
<td>1003</td>
<td>326</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>893</td>
<td>1246</td>
<td>353</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>567</td>
<td>983</td>
<td>416</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>868</td>
<td>1444</td>
<td>576</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>855</td>
<td>1464</td>
<td>609</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>907</td>
<td>1365</td>
<td>458</td>
<td></td>
</tr>
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<td>8</td>
<td>966</td>
<td>1874</td>
<td>908</td>
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<td>9</td>
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<td></td>
</tr>
<tr>
<td>10</td>
<td>570</td>
<td>922</td>
<td>352</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>1213</td>
<td>1876</td>
<td>663</td>
<td></td>
</tr>
</tbody>
</table>
The sustainability indicator of this aquifer is defined as:

\[ Csus = CR \cdot CRS \cdot (1 - CV) \]

Where:
- \( Csus \) : Sustainability indicator
- \( CR \) : Reliability indicator
- \( CRS \) : Resilience indicator
- \( CV \) : Vulnerability indicator

1) Estimate the values of the following indicators:

a) \( CR \)

b) \( CRS \)

c) \( CV \)

d) \( Csus \)

Hint:
- \( CR = n - m \)
- \( CRS = \frac{m_T}{n} \)
- \( CV = \left( \frac{SF}{\text{Abstraction}} \right)_{\text{max}} \)

Where:
- \( m \): Number of failure years.
- \( n \): Number of years.
- \( m_T \): The number of times, the system moved from unsatisfactory state to the satisfactory state.
- \( SF \): Shortfall in a failure period \( \Delta T \).
- \( \text{Abstraction} \): Total abstraction in the same failure period \( \Delta T \).
- \( \text{max} \): Maximum
2. (a) Based on the value of Csus from part (1), do you think the performance of the Western Aquifer Basin in meeting people’s needs is more or less sustainable? Why?

(b) If it is more sustainable or if it is less sustainable what do you recommend about abstraction scenarios?

(3) The historical values of renewable annual recharge of the Western Aquifer Basin suggest that the 10–year moving average (10-YMA) of that is 362 Mcm. What is the new sustainable yield of the Western Aquifer Basin?

Hint: Sustainable Yield = 0.9 × [10-YMA]

Where 10-YMA: 10–year moving average of annual recharge.