Ecosystem Accounting for Land, Water, Riparian, and Mineral Resources in Semi-Arid Climate Zones

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Abstract

Semi-arid climate zones present a unique and interesting scenario for consideration in ecosystem accounting. In the semi-arid zones, the availability of natural resources fluctuates during different seasons which creates both a challenge for adjusting physical flow accounts and an opportunity for directing meaningful natural resource management actions via monetary accounts. For example, river flow is seasonal, with water being present and available for storage during the wet season but potentially absent at other times of the year when the dry riverbed presents as a gully or canyon. This paper discusses how ecosystem accounting can effectively contribute to natural resource management in practice. Illustrated through a natural resource management framework featuring ecosystem services as the analytical unity, this paper points out the advantages of incorporating meteorological features of the semi-arid zones into ecosystem accounting for integrated and cumulative impact analyses in natural resource management.

Disclaimer: The opinions are those of the author and do not necessarily reflect the official position of the Bureau of Land Management, U.S. Department of the Interior.

1. Introduction

Semi-arid climate zones present a unique and interesting scenario for consideration in ecosystem accounting. In the semi-arid zones, the availability of natural resources fluctuates during different seasons. For example, river flow is seasonal, with water being present and available for storage during the wet season but potentially absent at other times of the year when the dry riverbed presents as a gully or canyon. This paper discusses how ecosystem accounting can effectively contribute to natural resource management in practice by incorporating the meteorological features of semi-arid zones. In Section 2, the typical meteorological features of semi-arid zones are presented, using the semi-arid zone in southwestern United States (U.S.) as an example. In Section 3, a natural resource management framework is utilized to illustrate the role of ecosystem accounting in integrated and cumulative impact analyses for natural resources management, contributing to monitoring and evaluation of sustainability and resilience of human societies in adaptation to ecosystem changes. Section 4 summarizes the advantages of incorporating the meteorological features of the semi-arid zones into ecosystem accounting for natural resource management.

2. Semi-Arid Zones

Semi-arid zones are distributed across the globe. These include eastern and northern Australia between 15-40 degrees south latitude, northern and western Asia between 10-50 degrees north latitude, western Europe and northern Africa between 35-45 degrees north latitude, northern Africa between 0-10 degrees north latitude, eastern Africa between 10 degrees north and 10 degrees south latitude, southern Africa between 15-35 degrees south latitude, eastern Brazil between 5-15 degrees south latitude, western South America between 20-40 degrees south latitude, and southwestern U.S. and northern Mexico between 20-50 degrees north latitude (**Figure 1**).

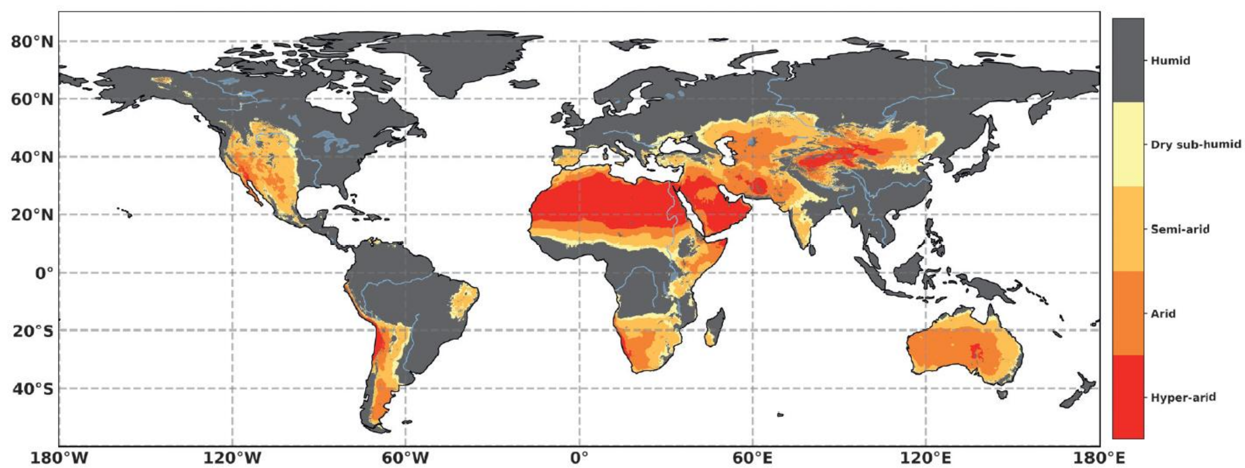

Figure 1. Semi-Arid Zones in the World

Source: IPCC, 2022, Climate Change and Land: an IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems; https://www.ipcc.ch/site/assets/uploads/sites/4/2022/11/SRCCL_Full_Report.pdf.

Taking the U.S. as an example, semi-arid zones have diverse landforms and associated ecosystems (**Figure 2**). They share some unique meteorological features. For example, more than two thirds of the year are dry days (**Figure 3**); total precipitation concentrates during the monsoon season (such as from June to September in the U.S.), whereas during the rest of the year there is very little or no precipitation (**Figure 4**).

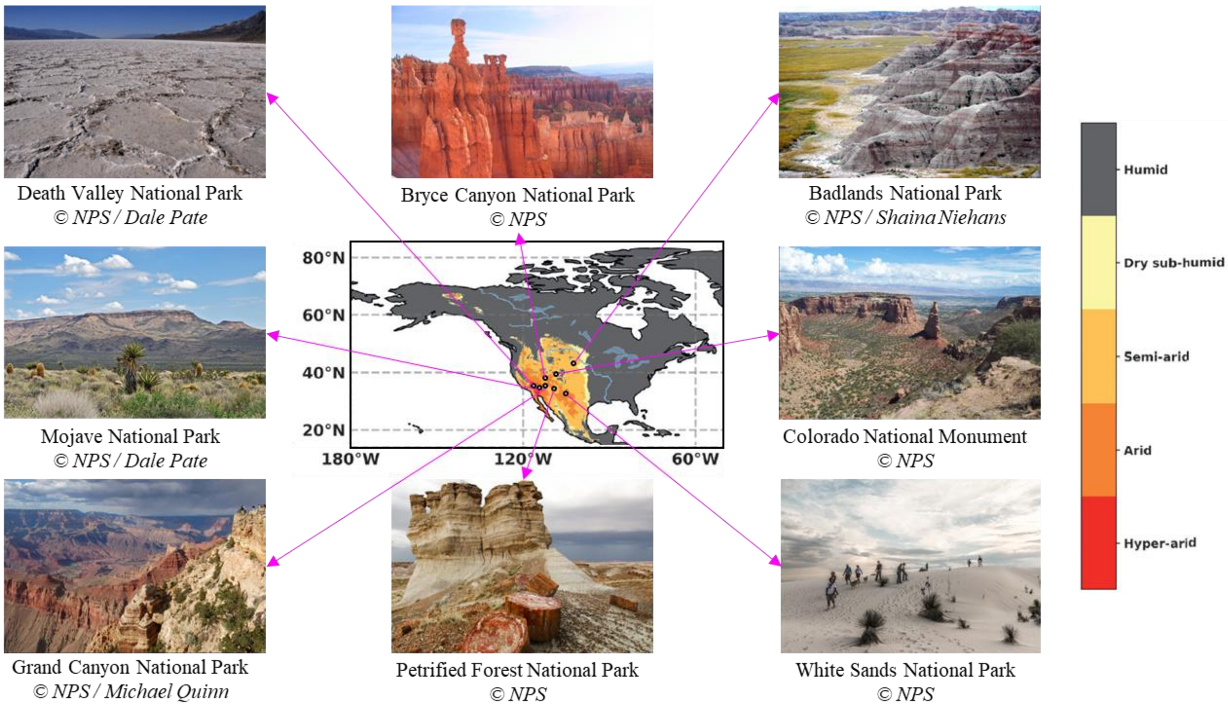

Figure 2. Diverse Landforms and Ecosystems in Semi-Arid Zones

Sources: based on IPCC, 2022, Climate Change and Land: an IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems, https://www.ipcc.ch/site/assets/uploads/sites/4/2022/11/SRCCL_Full_Report.pdf; U.S. National Parks Service, Arid and Semi-Arid Region Landforms, https://www.nps.gov/media/photo/gallery.htm?pg=5173831&id=06305DC6-4C58-4C92-9352-0FC82B769988, https://npgallery.nps.gov/AssetDetail/48f37a02-1dd8-b71b-0bb4-cb218908c4e1.

Figure 3. Unique Meteorological Features of Semi-Arid Zones – Dry Days

Source: based on Climate Explorer, https://crt-climate-explorer.nemac.org/.
Notes: (1) dry days are the number of days per year when precipitation is less than 0.01 inch; (2) higher emissions scenario is a possible future in which global emissions of heat-trapping gases continue to increase through 2100 (reaching 8.5 Watts per square meter in 2100); (3) lower emissions scenario is a possible future in which global emissions of heat-trapping gases peak around the year 2040 and then decrease (stabilizing at 4.5 Watts per square meter in 2100).

Figure 4. Unique Meteorological Features of Semi-Arid Zones – Total Precipitation

Source: based on Climate Explorer, https://crt-climate-explorer.nemac.org/.

One important implication of the meteorological features in these semi-arid zones is that the availability of specific natural resources fluctuates during different seasons (**Figure 5**). For example, because river flow is seasonal, water is present and available for storage during the wet season and can be used to support grazing and, when stored, can be used for riparian irrigation, extending the growing and grazing seasons; it is potentially absent at other times of the year when the dry riverbed presents as a gully or canyon which is often used for sand mining and mineral extraction. Thus, in terms of economic activity, the same portion of the landscape can provide both agricultural benefit as well as raw materials for construction and road building.

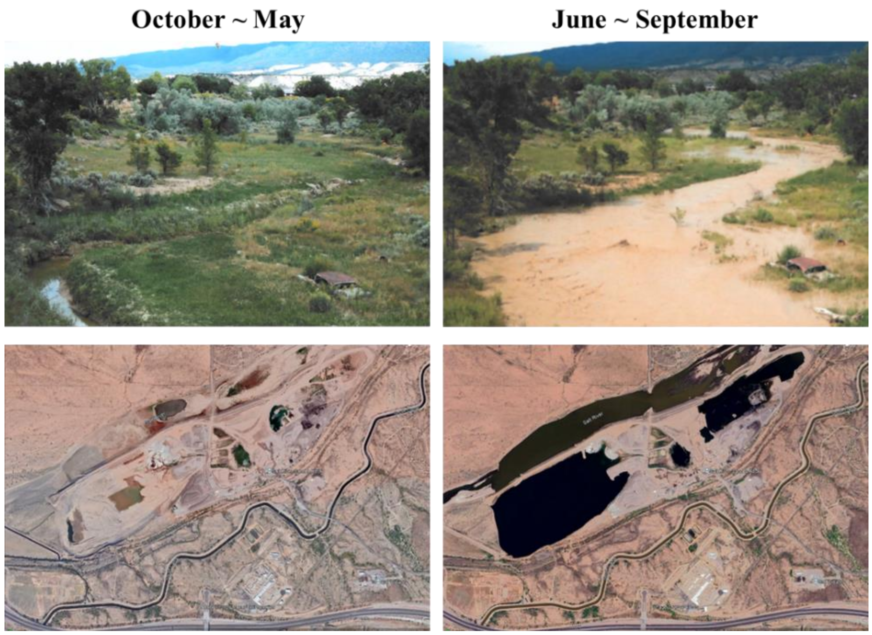

Figure 5. Seasonable Fluctuation of Natural Resources in Semi-Arid Zones

3. Natural Resource Management Framework

3.1 A Holistic Framework

The multiple roles that a single portion of the landscape play in semi-arid regions complicate their place in ecosystem accounting by acting both as aquatic resources and terrestrial resources depending on the time of year. To account for these significant differences in role, ecosystem accounting in natural resources management in these regions can be understood in terms of a holistic natural resource management framework (**Figure 6**) consisting of a circle of six steps (**Figure 7**).

- Step 1: recognizing that natural resource management involves multiple interrelated scientific disciplines and databases (**Figure 8**)
- Step 2: recognizing that natural resources are the foundation for economic outputs and other elements of human well-being (**Figure 9**)
- Step 3: utilizing ecosystem services as an analytical unity for natural resource management (**Figure 10**)
- Step 4: utilizing ecosystem accounting to analyze integrated impacts and cumulative impacts from management actions on human societies (**Figure 11**)

- Step 5: incorporating meteorological features of semi-arid zones to test dynamic models and understand tradeoff decisions (**Figure 12**)
- Step 6: incorporating meteorological features of semi-arid zones into the monitoring and evaluation of sustainability and resilience of human societies in adaptation to ecosystem changes (**Figure 13**)

Incorporating the unique meteorological features of semi-arid zones into this framework means that the multiple roles played by a single geographic resource can be defined and quantified to better ensure their true economic role and benefit in any given location. **Figure 6** provides an overview of the linkages between ecosystem services, natural resource management, and socioeconomic systems. Meteorological features have a direct connection to renewable resources and an indirect connection to resources such as paleontological resources, for example, which frequently are exposed during flooding events due to erosion. As suggested above, the seasonality of rainfall, for instance, can have a significant impact on agriculture, forestry and grazing. This impact translates into economic terms through modifying the production cycles and total productivity in a manner that differs greatly from the more consistent production cycles commonly observed in more temperate regions, where rivers flow year-around and production is more evenly spread throughout the year. This is further shown in **Figure 7**.

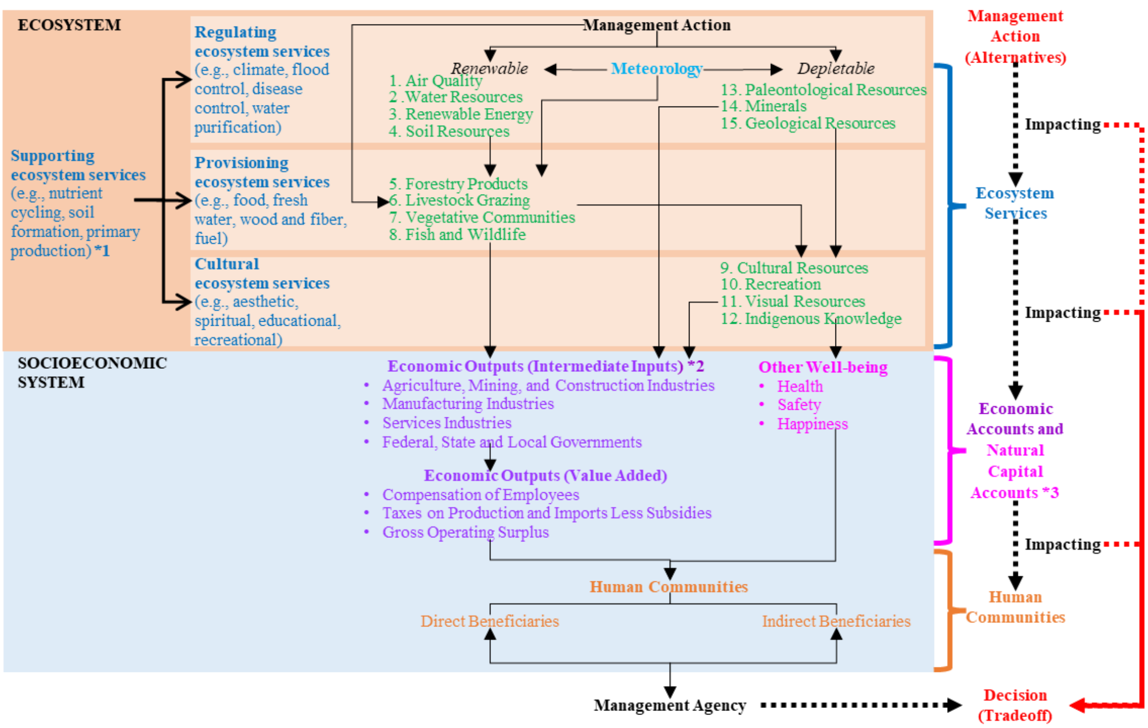

Figure 6. Natural Resource Management Framework: Overview

*Notes: *1 - Millennium Ecosystem Assessment (MEA), 2005, Ecosystems and Human Well-being, Island Press, Washington, D.C. https://www.millenniumassessment.org/en/Reports.html. *2 - the structure of the economic outputs is based on U.S. Bureau of Economic Analysis (BEA), 2011, Measuring the Nation's Economy: An Industry Perspective, A Primer on BEA's Industry Accounts. https://www.bea.gov/sites/default/files/methodologies/industry_primer.pdf.* *3 - The White House, 2023, *A U.S. System Of Natural Capital Accounting And Associated Environmental Economic Statistics*, https://www.whitehouse.gov/wp-content/uploads/2023/01/Natural-Capital-Accounting-Strategy-final.pdf.

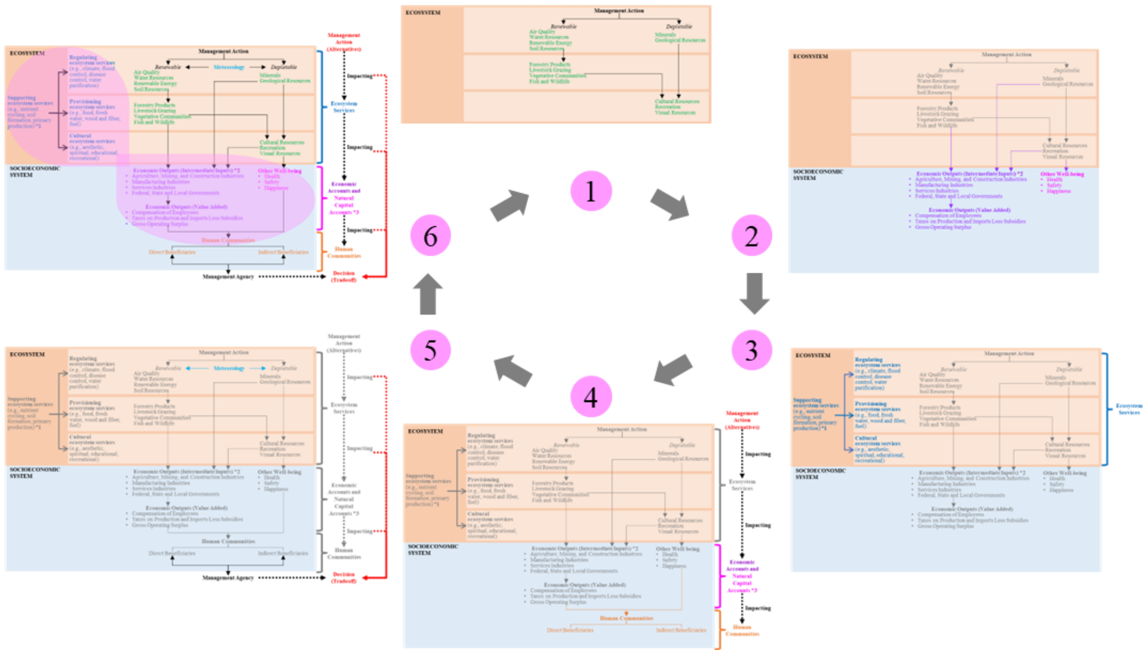

Figure 7. Natural Resource Management Framework: Incorporating Ecosystem Accounting in Six Steps

These six steps are further elaborated in **Figures 8** through **13**. Natural resource management involves various programs including (1) Air Quality, (2) Water Resources, (3) Renewable Energy, (4) Soil Resources, (5) Forestry Products, (6) Livestock Grazing, (7) Vegetative Communities, (8) Fish and Wildlife, (9) Cultural Resources, (10) Recreation, (11) Visual Resources, (12) Indigenous Knowledge, (13) Paleontological Resources, (14) Minerals, (15) Geological Resources, and (16) Socioeconomics (**Figure 8**). The natural resources from all these programs are the foundation for economic outputs and other elements of human well-being (**Figure 9**). For example, the presence or absence of water can be directly linked to the likelihood of forest and rangeland fires, which affect human health through the presence of particulates in the atmosphere. These same particulates, at different times of the year, can form nuclei around which water droplets can form, leading to rainfall events. The rainfall events, in turn, can promote vegetative growth supporting grazing and cattle and wildlife reproduction. Wildlife reproduction, especially, can contribute to tourism and support cultural ceremonies that build the fabric of human society. On the other hand, the terminology of ecosystem services provides an analytical unity across various natural resource programs (**Figure 10**). Through the Millennium Ecosystem Assessment (https://www.millenniumassessment.org/en/Reports.html) in 2005, the global scientific community defined ecosystem services as the benefits from ecosystems to human societies, including supporting ecosystem services, regulating ecosystem services, provisioning ecosystem services, and cultural ecosystem services. In particular, regulating ecosystem services are closely related to (1) Air Quality, (2) Water Resources, (3) Renewable Energy, (4) Soil Resources programs in the renewable resource domain, and (13) Paleontological Resources, (14) Minerals, (15) Geological Resources programs in the depletable resource domain. Provisioning ecosystem services are closely related to (5) Forestry Products, (6) Livestock Grazing, (7) Vegetative Communities, and (8) Fish and Wildlife programs. Cultural ecosystem services are closely related to (9) Cultural Resources, (10) Recreation, (11) Visual Resources, and (12) Indigenous Knowledge programs. Supporting ecosystem services form the foundation for all the programs. Ecosystem services can be measured via economic accounts and natural capital accounts to analyze integrated impacts and cumulative impacts from management actions on human societies (**Figure 11**). Economic accounts (https://www.bea.gov/sites/default/files/methodologies/industry_primer.pdf) have been applied by the U.S. Bureau of the Economic Analysis for decades whereas natural capital accounts (https://www.whitehouse.gov/wp-content/uploads/2023/01/Natural-Capital-Accounting-Strategy-final.pdf) in the U.S. have been initiated by the White House since 2023. Incorporation of meteorological features of semi-arid zones allows testing dynamic models connecting meteorology with the natural resource programs in the renewable domains as well as the depletable domains and understanding tradeoff decisions under different long-run and short-run scenarios (**Figure 12**). It also allows monitoring and evaluation of sustainability and resilience of human societies in terms of the structural changes of economic outputs and natural capital, in adaptation to ecosystem changes in terms of the structural changes of ecosystem functions and ecosystem services (**Figure 13**).

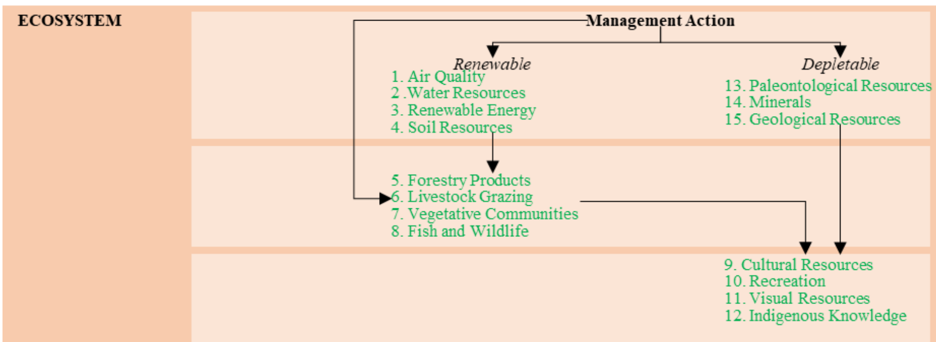

Figure 8. Incorporating Ecosystem Accounting Step 1

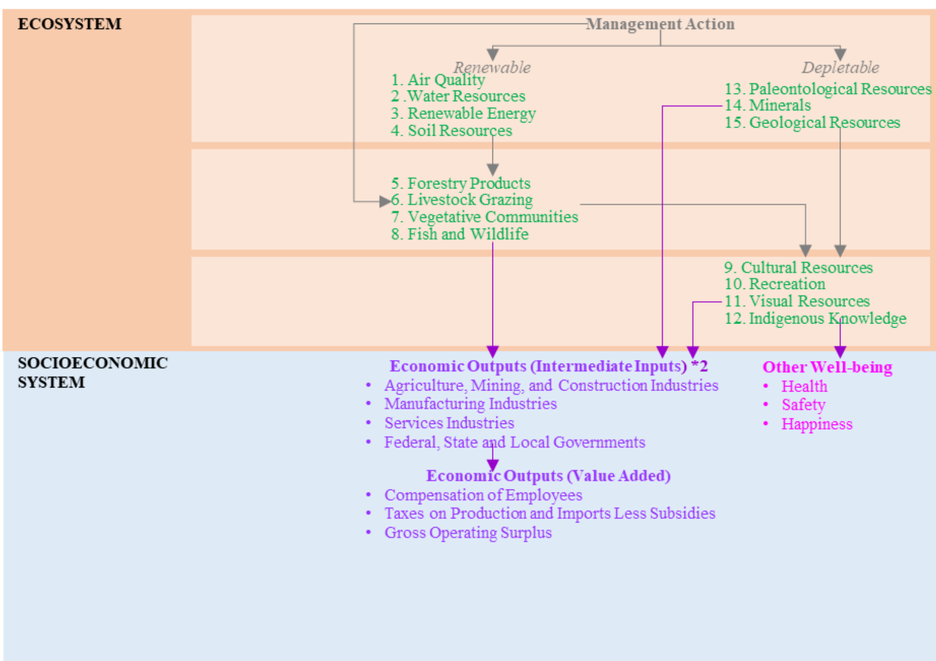

Figure 9. Incorporating Ecosystem Accounting Step 2

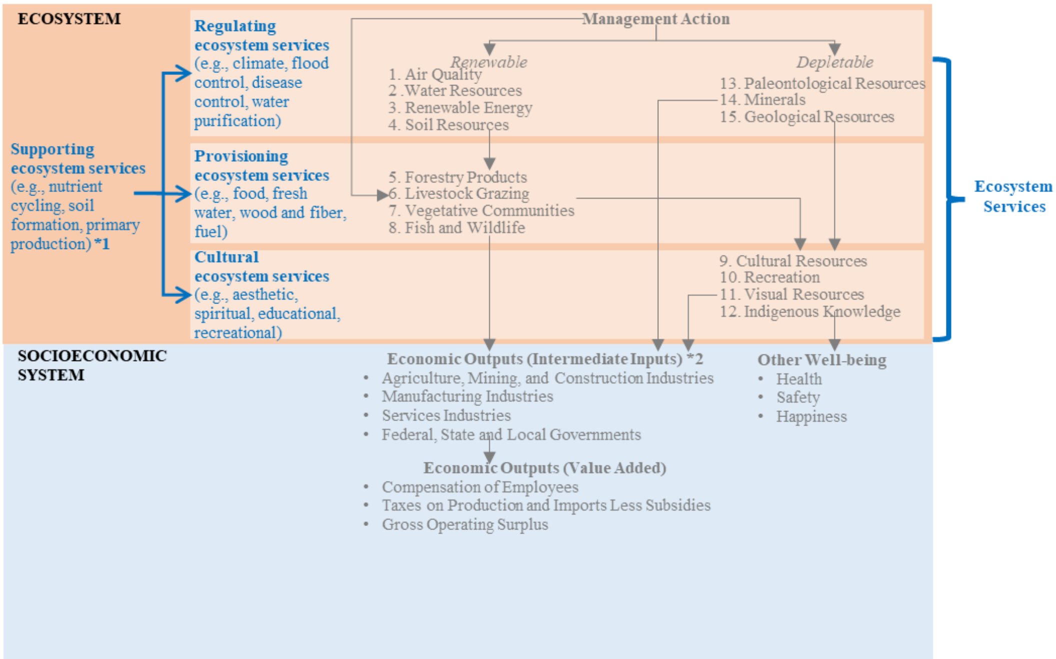

Figure 10. Incorporating Ecosystem Accounting Step 3

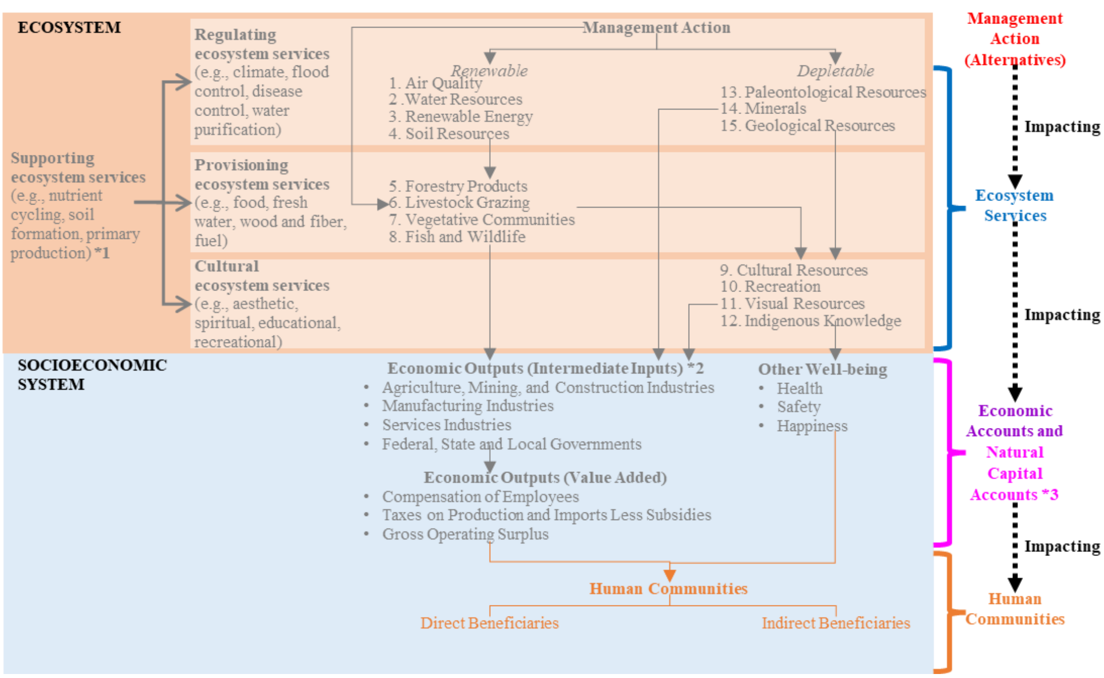

Figure 11. Incorporating Ecosystem Accounting Step 4

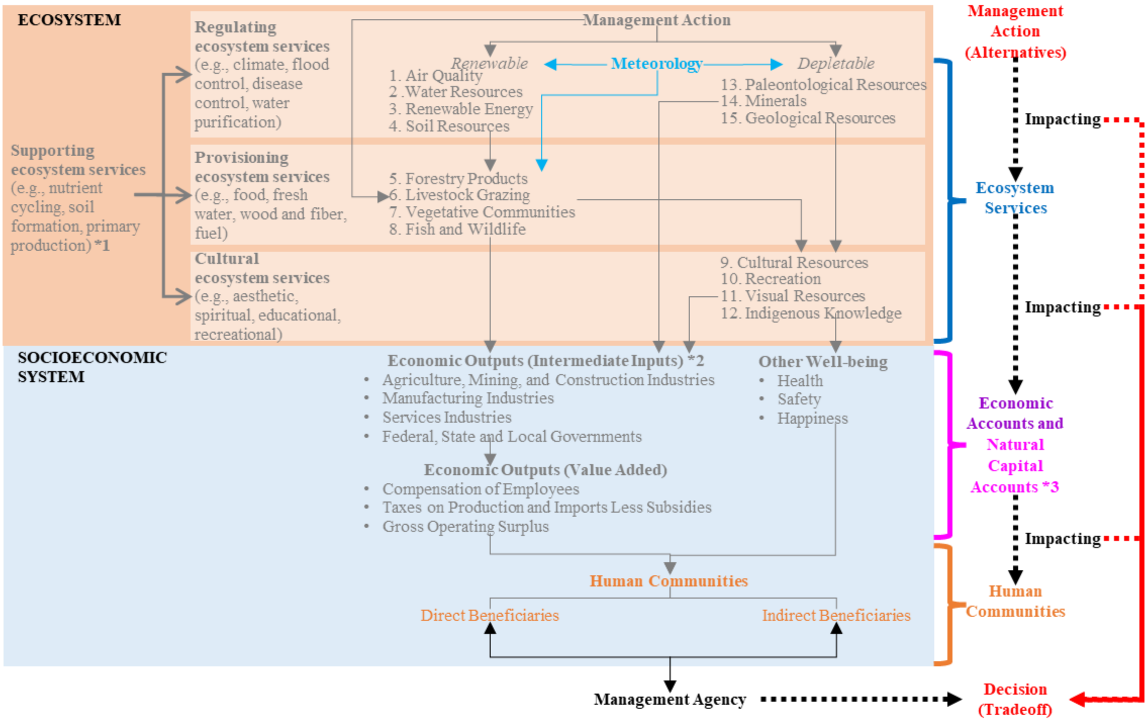

Figure 12. Incorporating Ecosystem Accounting Step 5

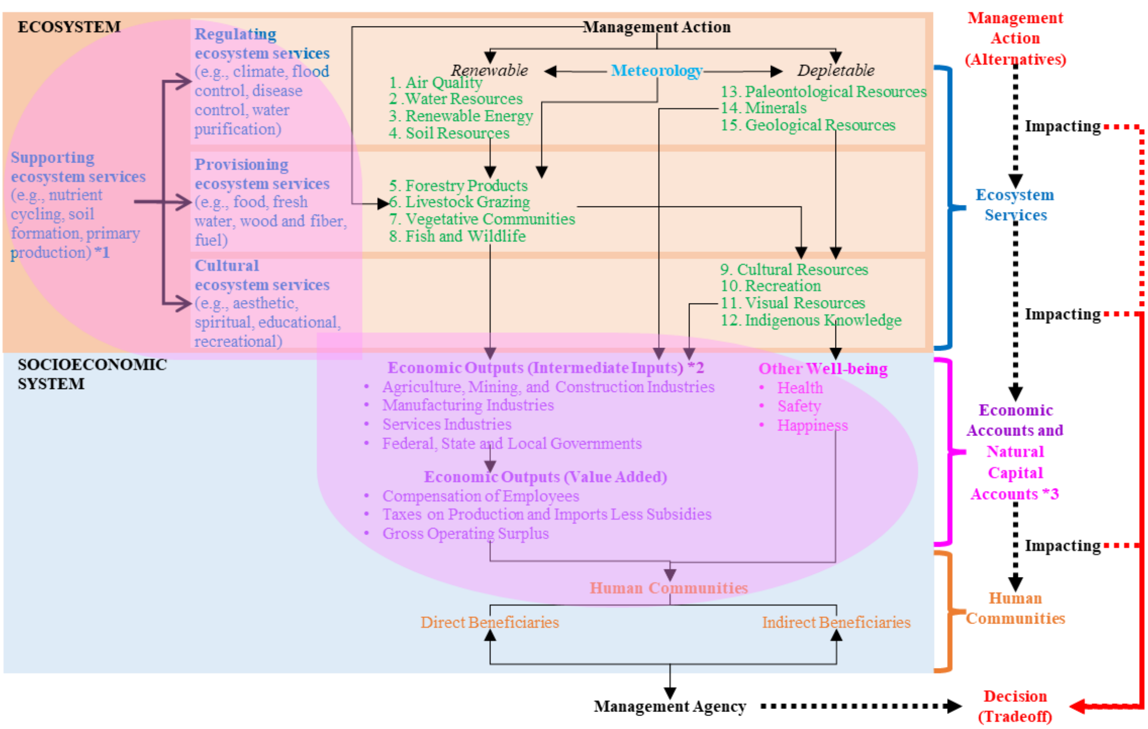

Figure 13. Incorporating Ecosystem Accounting Step 6

3.2 A Hypothetical Example

This section uses a hypothetical example to illustrate how to apply the natural resource management framework through a logical structure of impact analysis based upon 12 key diagnostic questions designed to elaborate the various features discussed above (**Figure 14**).

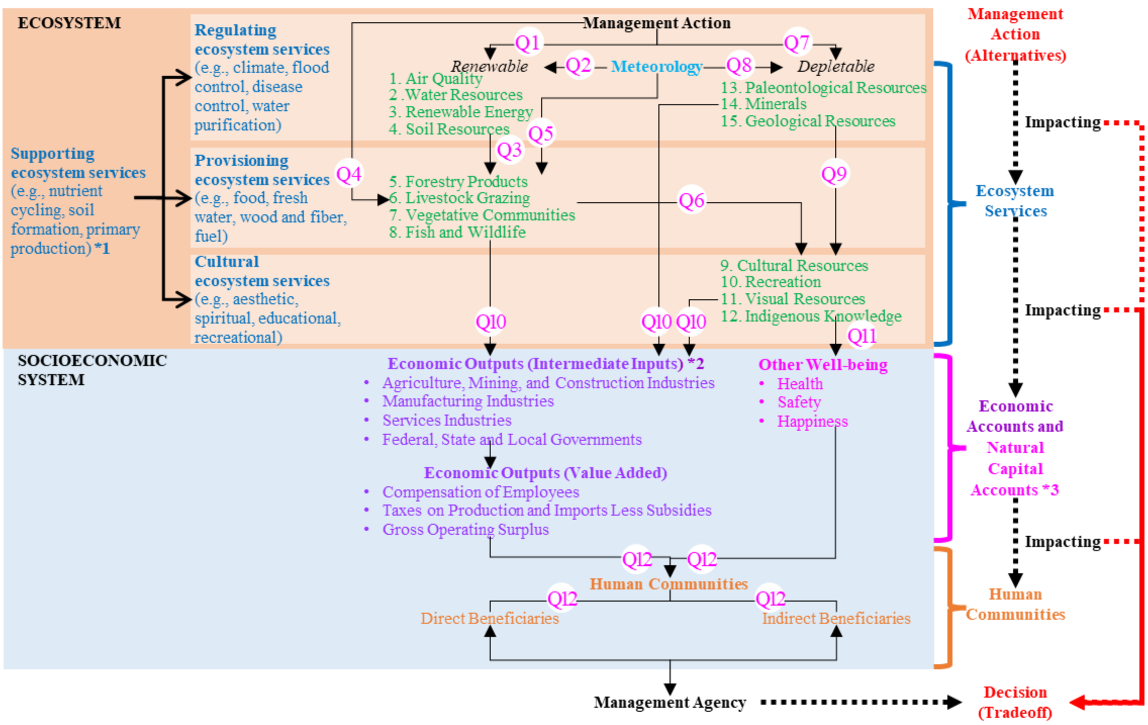

Figure 14. Hypothetical Example: Impact Analysis

*Notes: *1 - Millennium Ecosystem Assessment (MEA), 2005, Ecosystems and Human Well-being, Island Press, Washington, D.C. https://www.millenniumassessment.org/en/Reports.html. *2 - the structure of the economic outputs is based on U.S. Bureau of Economic Analysis (BEA), 2011, Measuring the Nation's Economy: An Industry Perspective, A Primer on BEA's Industry Accounts. https://www.bea.gov/sites/default/files/methodologies/industry_primer.pdf. *3 -* The White House, 2023, *A U.S. System Of Natural Capital Accounting And Associated Environmental Economic Statistics*, https://www.whitehouse.gov/wp-content/uploads/2023/01/Natural-Capital-Accounting-Strategy-final.pdf. *Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12 – key questions for impact analyses.*

(A) Context

The U.S. National Environmental Policy Act (NEPA) provides the basic requirement that natural resource management actions consider the impacts of such actions within the broader context of human society. An office developing an Environmental Assessment under NEPA is required to consider the appropriate extent of livestock grazing on the land of a National Monument so that livestock grazing is compatible with the ecosystem (forests, grasslands, plants, wildlife, archaeological and historic sites) within the National Monument.

(B) Management Action Alternatives

Three alternatives of management actions are commonly considered, where livestock grazing refers to the maximum number of animal unit months (AUMs) allowed at any given time throughout a year. In semi-arid regions, the period to be considered can vary depending on the duration of the wet and dry seasons.

- Alternative A: maintaining the current livestock grazing size
- Alternative B: reducing the livestock grazing size to 50% of the current grazing size
- Alternative C: stopping livestock grazing

(C) Meteorological Trend in the Project Area

Recent data indicate that, in the past decade, the meteorological conditions in the project area suggest that the area is getting drier in terms of less precipitation and more dry days in a year.

(D) Impact Analysis

The impact analysis will generate findings based upon the changes proposed under Alternative B and Alternative C, respectively, and comparing these with the baseline under Alternative A, the baseline scenario. Note that in this example, the identified types of impacts under Alternative B and Alternative C as presented in Tables 1 through 5 are similar, but the findings of impacts under Alternative B and Alternative C will be different (at least in scale). In addition, the identified impacts should be verified and specified, and they should be measured or quantified whenever possible. Furthermore, for other examples, the identified types of impacts under the different alternatives will most likely be different as well. These considerations affect the various analyses and can be explored through the basic questions identified under each stage of the analysis:

- Impact analysis part 1: from regulating ecosystem services to provisioning ecosystem services, Questions 1 through 3 (**Figure 15**, **Table 1**)
- Impact analysis part 2: from provisioning ecosystem services to cultural ecosystem services, Questions 4 through 6 (**Figure 16**, **Table 2**)
- Impact analysis part 3: from regulating ecosystem services to cultural ecosystem services, Questions 7 through 9 (**Figure 17**, **Table 3**)
- Impact analysis part 4: from ecosystem services to economic and natural capital, Questions 10 through 11 (**Figure 18**, **Table 4**)
- Impact analysis part 5: from economic and natural capital to human communities, Question 12 (**Figure 19**, **Table 5**)

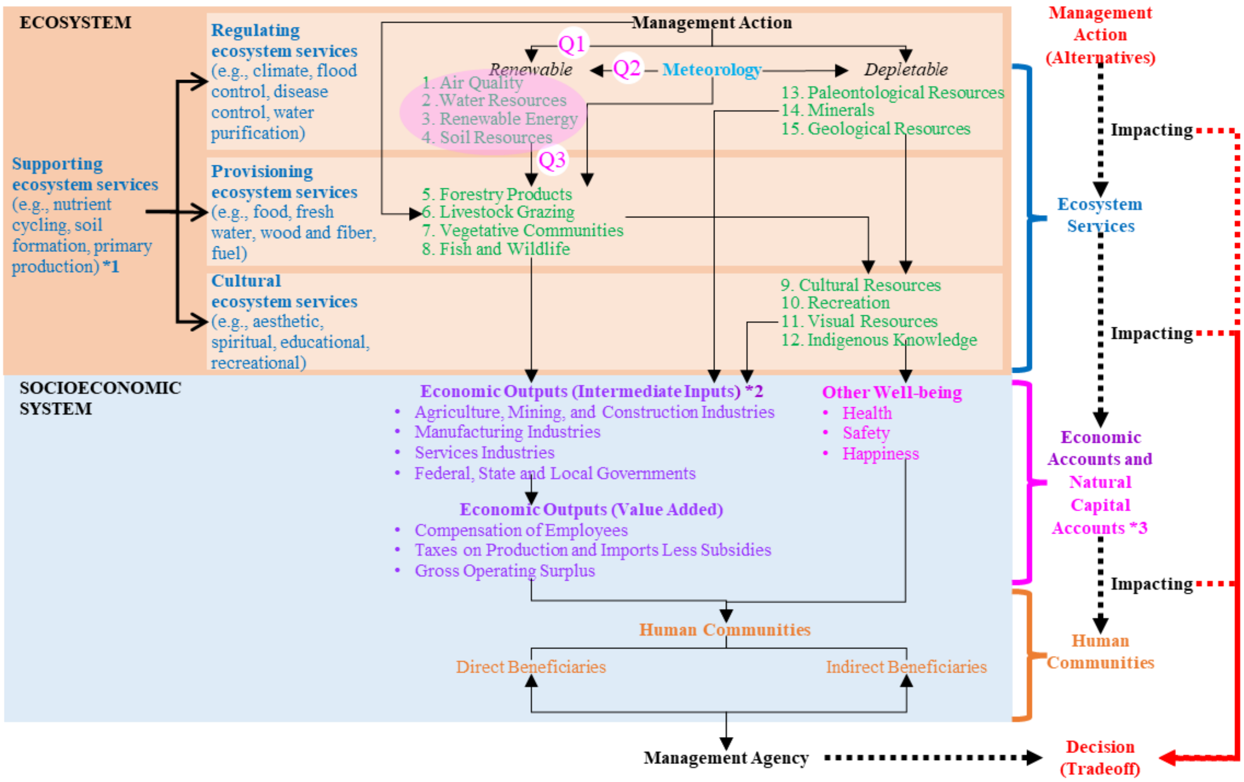

Figure 14. Hypothetical Example: Impact Analysis Part 1

Table 1. Hypothetical Example: Impact Analysis Part 1

Analysts: subject matter experts for programs (1) through (4).		(1) Air Quality	(2) Water Resources	(3) Renewable Energy	(4) Soil Resources
Question 1: Does the proposed action affect the **regulating ecosystem services** (e.g., climate, flood control, disease control, water purification) related to the programs (1) through (4)? If yes, describe the impacts on the respective **regulating ecosystem services**.		Reduction of AUMs causes reduction of methane (GHG)	Reduction of AUMs causes reduction of water use by livestock		Reduction of AUMs reduces soil erosion and speeds up soil recovery
Question 2: Does climate change affect the other **regulating ecosystem services** (e.g., flood control, disease control, water purification) related to the programs (1) through (4)? If yes, describe the impacts on the respective **regulating ecosystem services**.			Dryer climate reduces water availability		Dryer climate reduces soil moisture
Question 3: Do the changes of regulating ecosystem services related to the programs (1) through (4) affect the **provisioning ecosystem services** (e.g., food, fresh water, wood and fiber, fuel) related to the programs (5) through (8)? If yes, describe the impacts on the respective **provisioning ecosystem services**.	(5) Forestry Products		Overall increases of water availability causes increase of timber growth		Overall improved soil quality causes increase of timber growth
	(6) Livestock Grazing				
	(7) Vegetative Communities		Overall increases of water availability causes plant growth		Overall improved soil quality causes plant growth
	(8) Fish and Wildlife				

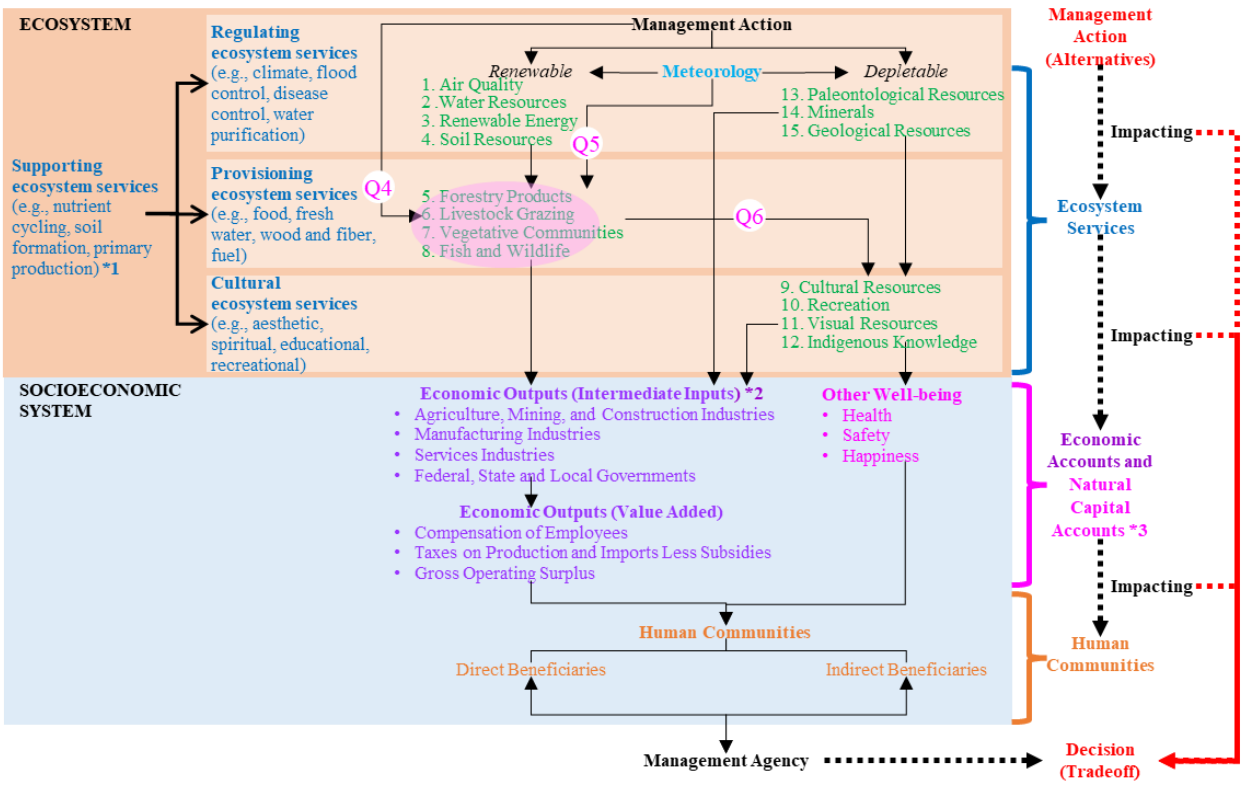

Figure 15. Hypothetical Example: Impact Analysis Part 2

Table 2. Hypothetical Example: Impact Analysis Part 2

Analysts: subject matter experts for programs (5) through (8).		(5) Forestry Products	(6) Livestock Grazing	(7) Vegetative Communities	(8) Fish and Wildlife
Question 4: Does the proposed action affect the provisioning ecosystem services (e.g., food, fresh water, wood and fiber, fuel) related to the programs (5) through (8)? If yes, describe the impacts on the respective provisioning ecosystem services.			Reduction of AUMs	Reduction of AUMs speeds up grass recovery	
Question 5: Does climate change affect the provisioning ecosystem services (e.g., food, fresh water, wood and fiber, fuel) related to the programs (5) through (8)? If yes, describe the impacts on the respective provisioning ecosystem services.				Dryer climate reduces grass growth	
Question 6: Do the changes of provisioning ecosystem services related to the programs (5) through (8) affect the cultural ecosystem services (e.g., aesthetic, spiritual, educational, recreational) related to the programs (9) through (12)? If yes, describe the impacts on the respective cultural ecosystem services.	(9) Cultural Resources				
	(10) Recreation				
	(11) Visual Resources			Overall increases of grass growth improves the landscape scenery	
	(12) Indigenous Knowledge				

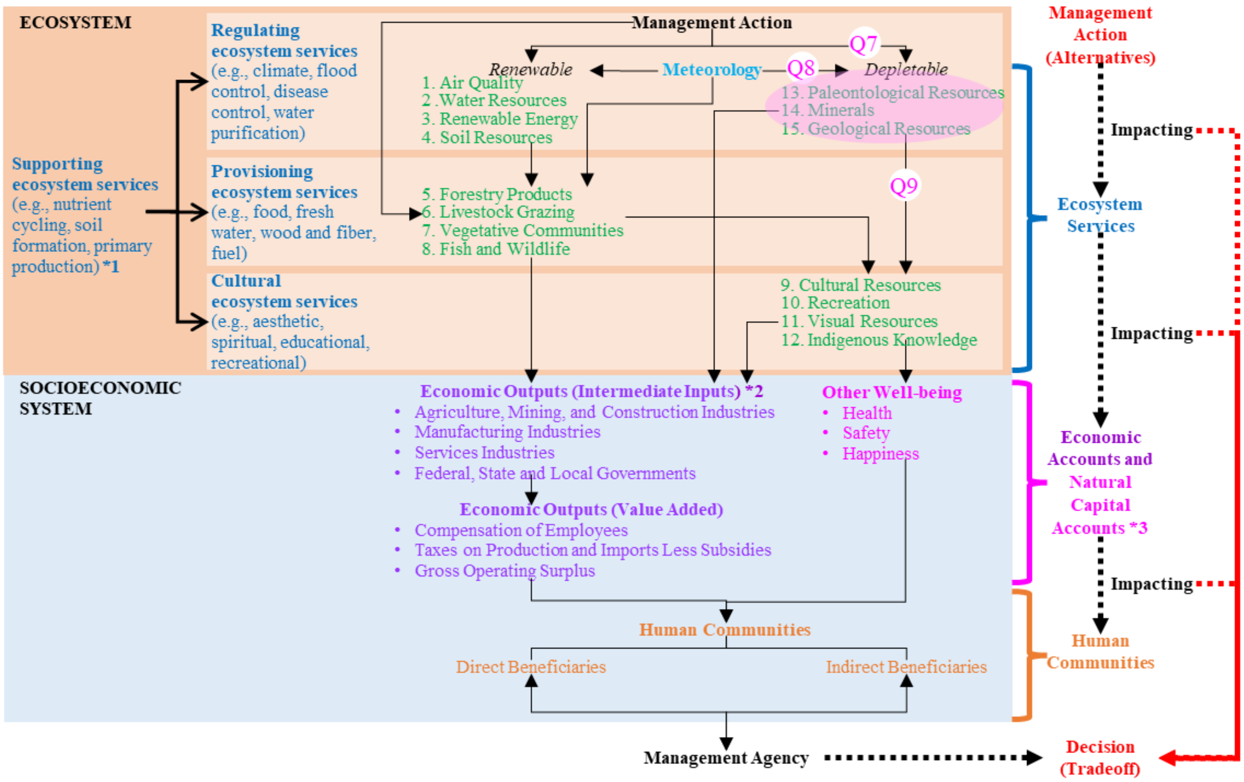

Figure 16. Hypothetical Example: Impact Analysis Part 3

Table 3. Hypothetical Example: Impact Analysis Part 3

Analysts: subject matter experts for programs (13) through (15).		(13) Paleontological Resources	(14) Minerals	(15) Geological Resources
Question 7: Does the proposed action affect the regulating ecosystem services (e.g., climate, flood control, disease control, water purification) related to the programs (13) through (15)? If yes, describe the impacts on the respective regulating ecosystem services.		Reduction of soil erosion may increase likelihood of paleontological resource discovery and reduce likelihood of their loss		
Question 8: Does climate change affect the other regulating ecosystem services (e.g., flood control, disease control, water purification) related to the programs (13) through (15)? If yes, describe the impacts on the respective regulating ecosystem services.				
Question 9: Do the changes of provisioning ecosystem services related to the programs (13) through (15) affect the cultural ecosystem services (e.g., aesthetic, spiritual, educational, recreational) related to the programs (9) through (12)? If yes, describe the impacts on the respective cultural ecosystem services.	(9) Cultural Resources	Higher likelihood of paleontological resource discovery increases cultural resources values		
	(10) Recreation	Reduced loss of paleontological resources increases recreation activities		
	(11) Visual Resources			
	(12) Indigenous Knowledge	Reduced loss of paleontological resources reduces concerns of indigenous communities		

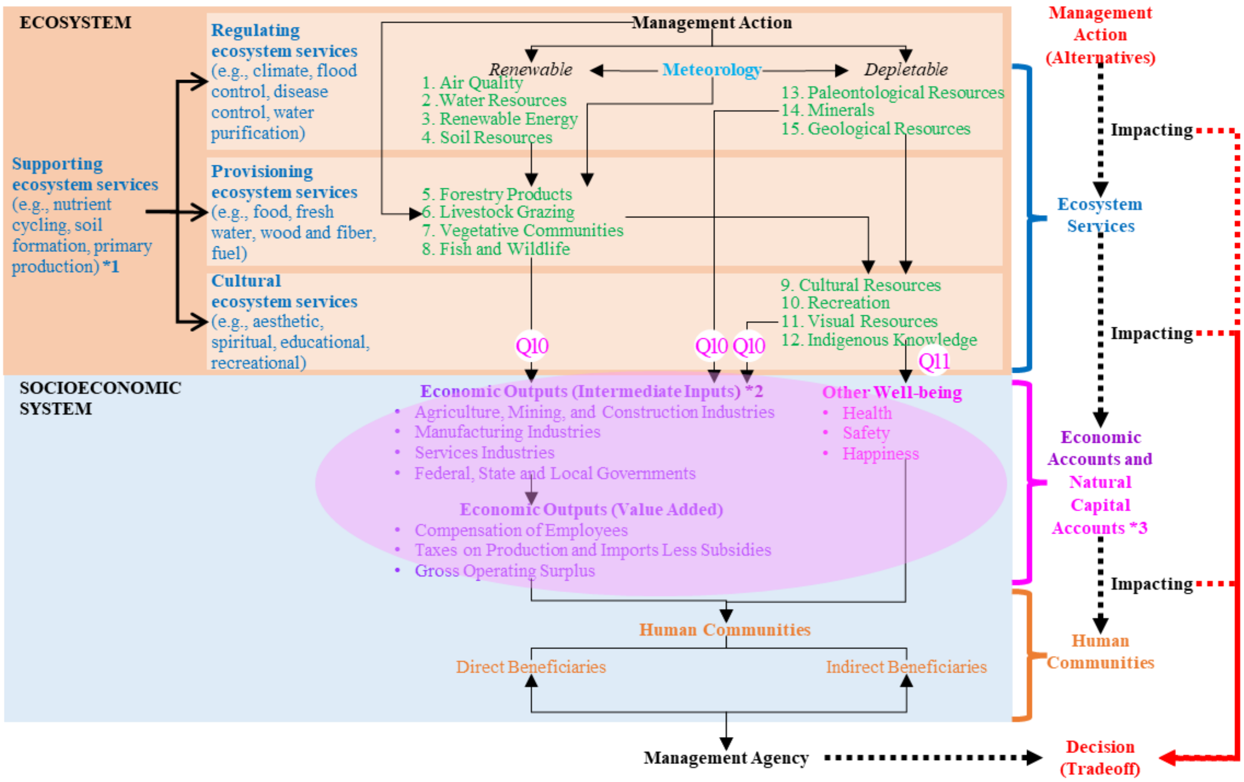

Figure 17. Hypothetical Example: Impact Analysis Part 4

Table 4. Hypothetical Example: Impact Analysis Part 4

Analysts: subject matter expert for program (16).		(16) Socioeconomics
Question 10: Do the changes of provisioning ecosystem services related to the programs (5) through (8), changes of regulating ecosystem services related to the programs (13) through (15), and changes of cultural ecosystem services related to the programs (9) through (12) affect economic outputs? If yes, describe the impacts on economic outputs.	Economic Outputs	Overall changes in animal products, timber, and recreation activities affect economic outputs in agriculture, recreation, and service sectors, which in turn affect economic outputs in other sectors, which altogether affect value added including salaries and profits to communities, and taxes to governments in the area.
Question 11: Do the changes of cultural ecosystem services related to the programs (9) through (12) affect other well-being (e.g., health, safety, happiness)? If yes, describe the impacts on the other well-being.	Other Well-being	Overall changes in cultural resources, recreation, and indigenous knowledge affect well-being of communities in the area.

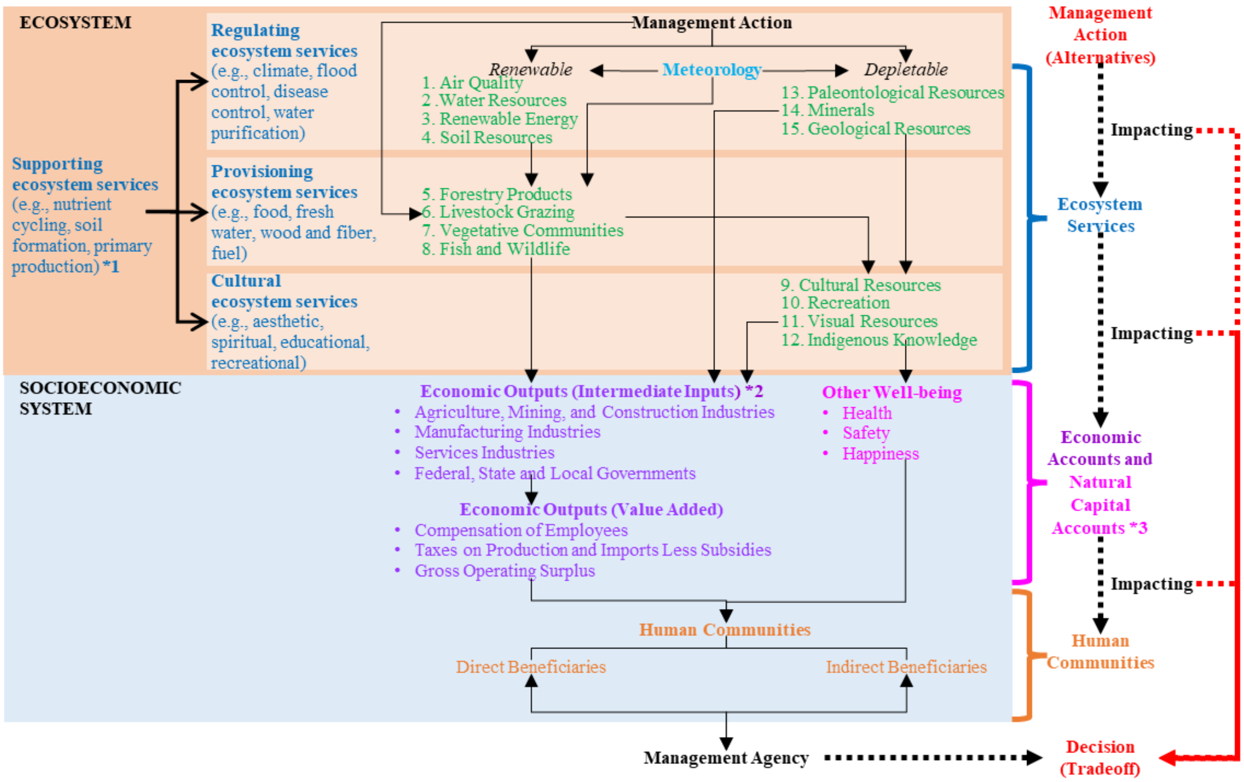

Figure 18. Hypothetical Example: Impact Analysis Part 5

Table 5. Hypothetical Example: Impact Analysis Part 5

Analysts: subject matter expert for program (16).		(16) Socioeconomics
Question 12: Do the changes of economic outputs and other well-being affect **direct beneficiaries** and **indirect beneficiaries**? If yes, describe the **impacts** and potential **mitigation measures**.	Communities	Overall changes to economic outputs and other well-being in the area may distribute disproportionally among direct beneficiaries and indirect beneficiaries depending on the geographical locations of the communities and the industrial sector activities of the communities.

(E) Tradeoff and Decision

Based on the findings, Alternative B and Alternative C can be evaluated against Alternative A. Specifically, the findings can include the size of net benefits for each alternative, the distributions of net benefits between direct beneficiaries and indirect beneficiaries for each alternative, and the tradeoff between different alternatives, such as one alternative with higher net benefits but higher disproportional impacts versus another alternative with lower net benefits but lower disproportional impacts on communities. The findings then can be used to support decision-making.

4. Summary

Evaluating the economic impacts of natural resource management in semi-arid zones presents several challenging elements. In particular, natural resource features in these regions can take the form of several types of ecosystems, depending on season and the availability of water. Ecosystem accounting provides an important contribution to integrated and cumulative impact analyses in natural resource management. Incorporating the meteorological features of semi-arid zones into ecosystem accounting is crucial and has many advantages including, especially, the following aspects: advancing the natural and social sciences, developing interdisciplinary databases for both physical and monetary accounts, testing dynamic models, implementing effective applications, understanding tradeoff decisions, contributing to decision-making at all levels, and contributing to sustainability and resilience measures.