4. DESCRIPTION OF ENVIRONMENTAL COMPONENTS THAT ARE LIKELY TO BE SIGNIFICANTLY AFFECTED BY A PROPOSED ACTIVITY OR ITS ALTERNATIVES

4.1. Methodology Employed to Assess the Impact of the Navigation Route Project on Various Environmental Components

The review and analysis of environmental impacts of navigation route are based on the impact structure with a central element thereof being a suite of processes that may be triggered in the environment through the interaction of impact factors with environmental factors (Figure 4.1).

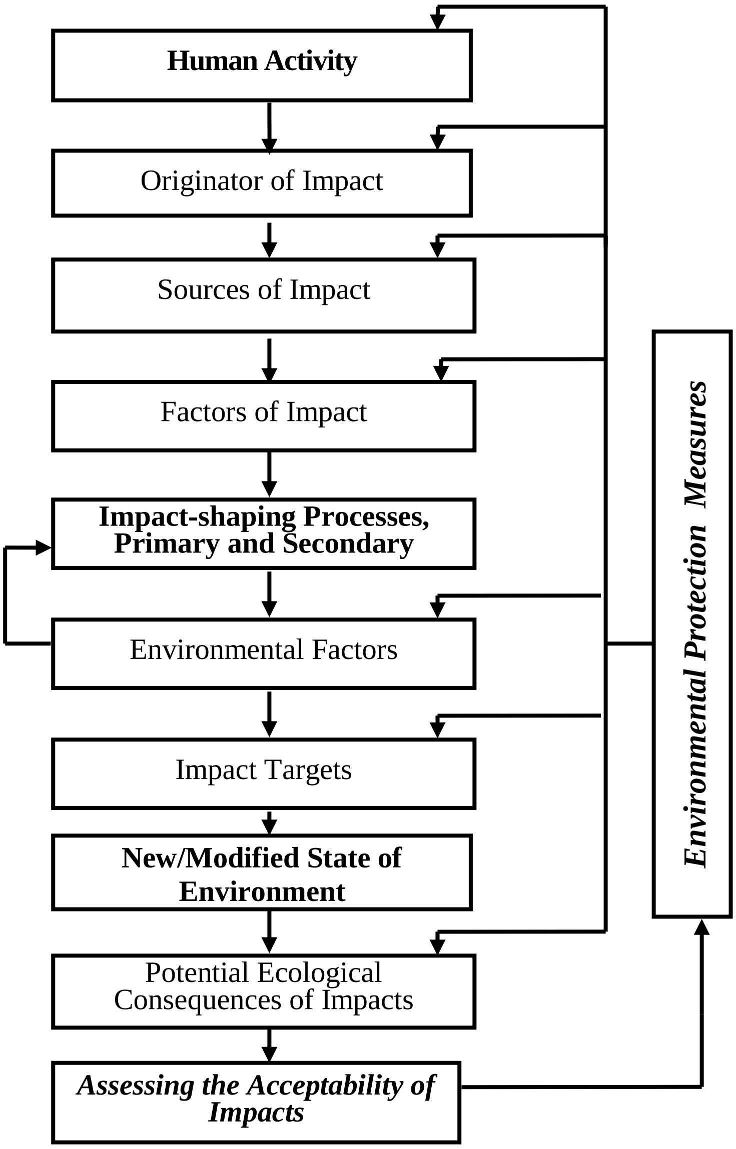

Figure 4.1. Impact Management Structure

Impact-shaping processes represent a complex web of physical, chemical and biological processes of various order: a primary process is defined as a process that is triggered directly by a factor of impact, whereas a secondary, or indirect, process is caused by a primary process and results thereof represent the factors of impact that cause a secondary process.

The entire suite of environmental impacts associated with the Navigation Route Project was examined and reviewed in detail using the approach graphically illustrated in Figure 4.1. Tables 4.1

and 4.2 describe key elements that are considered to be of direct relevance to the factors and impacts that cause/shape the identified impacts.

Table 4.1. Factors Causing Environmental Impacts during the Development and Operation of the Navigation Route

Activity/Source of Impact	Impact Factors
1. Dredging/excavation activity within the river channel and along the seaward access channel. Dredged soil dumping (spoil islands, riparian dumps and offshore dump). Mobile plant and machinery operated in the project area	1.1. Bottom disturbance in the dredging areas (shallow sections of river channel, seaward access channel and retaining dam) 1.2. Bottom disturbance at the offshore dumpsite 1.3. Land loss/withdrawal to accommodate riparian dumps 1.4. Soil losses due to excavation and dredging 1.5. Dredged/dumped soil comes in contact with marine water 1.6. Release/inflow of surplus water from riparian dumps 1.7. Noise produced by mobile plant and machinery 1.8. Exhaust emissions produced by mobile plant and machinery
2. Maintenance dredging. Dredged soil dumping (spoil islands, riparian dumps and offshore dump). Mobile plant and machinery operated in the project area	2.1. Bottom disturbance in the dredging areas (shallow sections of river channel and seaward access channel) 2.2. Bottom disturbance at the offshore dumpsite 2.3. Land loss/withdrawal to accommodate riparian dumps 2.4. Soil losses due to excavation and dredging 2.5. Dredged/dumped soil comes in contact with marine water 2.6. Release/inflow of surplus water from riparian dumps 2.7. Noise produced by mobile plant and machinery 2.8. Exhaust emissions produced by mobile plant and machinery
3. Flow management structures and ship traffic	3.1. Presence of features shaping/affecting the delta development (sandbar opening and dam) 3.2. Modified channel morphometry and flow dynamics 3.3. Impact of waves caused by ship traffic 3.4. Accidental release of pollutants 3.5. Introduction of new flora and fauna species 3.6. Noise produced by mobile plant and machinery 3.7. Exhaust emissions produced by mobile plant and machinery

Table 4.2. Characterisation of Key Impact-Shaping Processes Associated with the Project

Impact Factors	Impact-shaping Processes
1.1, 1.2	I Destruction/loss of bottom benthic communities in some sections of the route
2.1, 2.2	II Change/modification of bottom and riverbank topography
1.3, 2.3	III Soil inwash at the riparian dumpsites
1.4, 2.4	IV Downstream transport of particulate matter flow and adsorbed pollutants
1.5, 2.5	V Destruction/loss of benthic communities in the area of offshore dumpsite. Periodic input of pollutants and nutrients in suspended and soluble forms to the marine water
1.6, 2.6	VI River water pollution due to rainstorm water runoff and surplus water release from dumpsites
1.7, 2.7, 3.6	VII Propagation of noise produced ship engines and project machinery in the air and water environment
1.8, 2.8, 3.7	VIII Increases in the near-ground concentrations of nitrogen oxides, carbon black, hydrocarbons, sulphurous anhydride, and carbon oxide
3.1	IX Changes in the natural course of the delta advancement process in the sandbar area
	X Increased inflow/invasion of saline marine water into the river channel
3.2	XI Generation/accumulation of solid substrate

	XII Potential redistribution of flow between the delta branches, increased intensity of upwelling/downwelling events
3.3	XIII Riverbank levee erosion
3.4	XIV Increased presence of oil films in the adjacent areas of the sea, elevated concentrations of pollutants in the marine water
3.5	XV Introduction/entry of new flora and fauna species into the benthic and riparian communities

4.2. Description of Environmental Conditions and Features Existing in the Project Impact Area, Review of Environmental Factors Considered to Interact with the Project Impacts, and Identification of Potential Environmental Consequences

The proposed navigation route runs along the Chilia Delta of the Danube that comprises an intricate and volatile pattern of river arms and enclosed areas of land (islands). Significant areas of these islands are waterlogged and covered by wetlands. The most elevated landforms are riparian levees and coastal spits, whose relative average altitudes range between 0.5 m to 1.0 m. The topography of the central sections of these islands is typically one of costal lowland plain, dissected by channels and lakes.

The riparian levees extend along river arms and shallow channels, and their asymmetric shapes are the result of erosive action of water flowing in the streams. On the majority of islands, steeper and higher slopes of levees typically lie closer to watercourses, while their lower slopes dip gently towards the centre of an island, thereby promoting its saucer-shaped topography. The progress of levee development directly depends upon the availability and volume of sediments carried with river flow, especially in the high-water periods when a significant proportion of sediment load is deposited over flooded river banks that are built up to form natural levees. This explains the fact that levees are significantly higher in the outer perimeter sections of islands where altitudes are between 1.0 m to 1.5 m, because the effect and intensity of floods are much weaker in the inner perimeter sections of islands where the average altitude is 0.5 m. Levees are dissected by numerous extinct streamlets and channels linking adjacent islands. Riparian levees accommodate the major proportion of forest and meadow systems that have developed in the Danube Delta.

Apart from riparian levees, coastal spits also represent an important element of local topography, being built up from the interactions between the watercourses and the sea. At their early development stage, these spits are not elevated above the surrounding landscape and relatively small in length (up to 1.5 km). Coastal spits play an important role in the development of freshwater creeks by isolating parts of shallow coastal areas and limiting the invasion of marine water in the as they grow larger. In the longer term, the upper section of a spit may merge with the riparian levee present at an adjacent island, to form a creek that may gradually evolve into a semi-enclosed water body. In line with the laws governing the alluvial process, coastal spits merge with the terrestrial topographic units of the Delta as they develop over time, and form part of topographic pattern of adjacent islands.

The general direction of the Delta evolution is shaped by the interactions between the river and the sea, with key of them manifesting themselves in the following processes that are of continuous nature:

- The advancement of maritime delta towards the sea;
- The emergence/disappearance of new/old delta arms, change in their number, and redistribution of river flow received by them;
- The development of shallow coastal sections (sandbars) traversing the mouths of river arms as a result of sediment deposition/re-deposition within the river/sea interaction zone;

- The shift in water regime of delta islands towards slower water exchange in wetland areas and progressive decrease in water levels over time as river arms die off and shrink in number.

In the period between 1955 and 1979, the delta advancement process in the Chilia Branch sub-delta was most intensive in the mouths of the Ochakiv and Starostambulske Branches (Figure 4.2), being less pronounced in the area of the Bystre (Novostambulske) Branch mouth [2]. By 1980, the total area of the delta was 348 km^2, with the 8.26 km^3 talus cone.

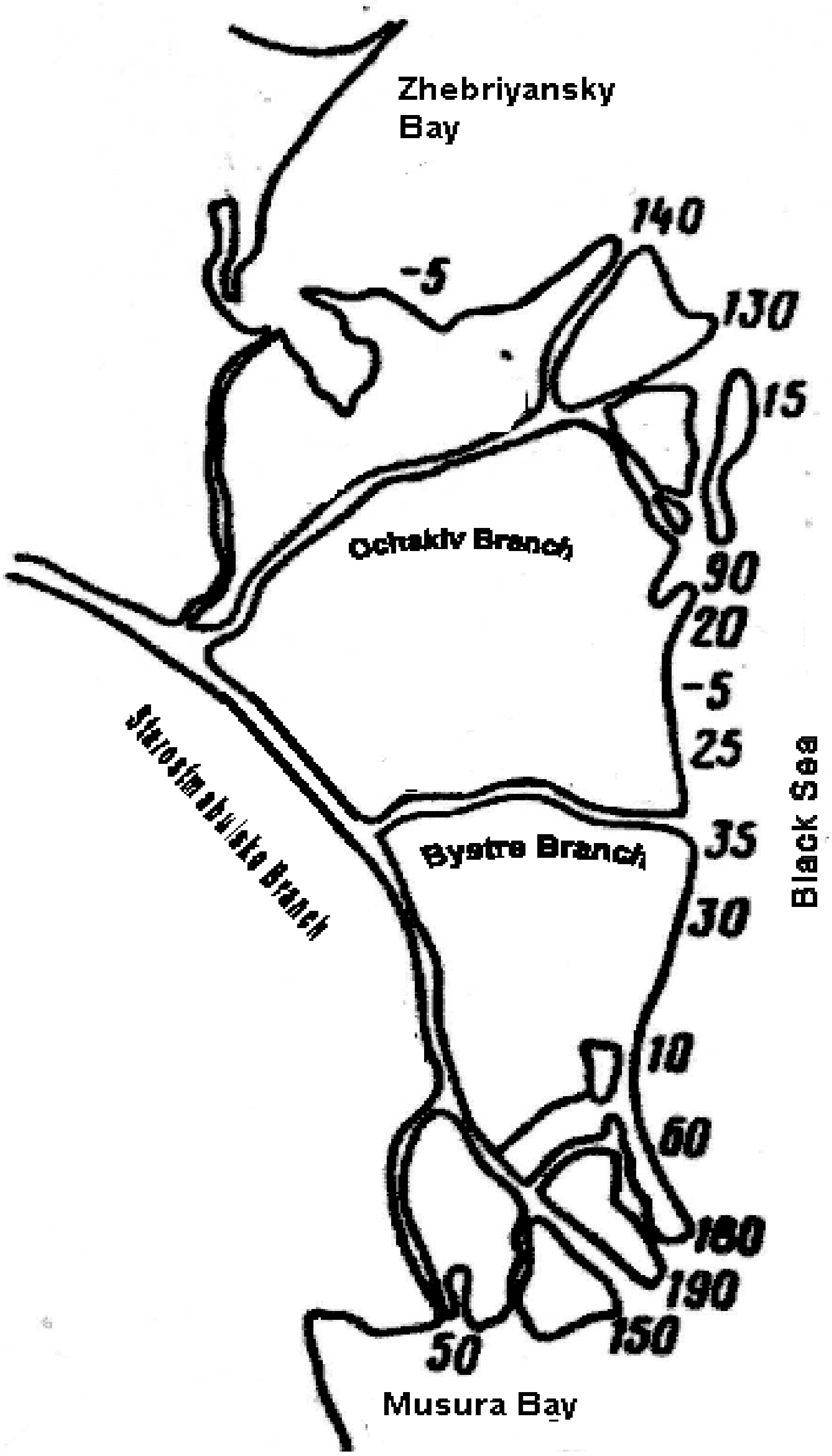

Figure 4.2. The Dynamics of the Chilia Delta Advancement
(figures specify annual average rates of delta edge advancement or recession (m/year)

By contrast, the rate of shoreline degradation near the Bystre and Skhidny (Eastern) Branches grew particularly high by the 1950s, reaching 10-15 m/years in some years [3].

The evolution of the Chilia Branch sub-delta comprised four successive phases: single-branch phase (1740-1800), few-branch phase when the number of branches was up to 20 (1800-1856), multi-branch phase when the number of branches ranged between 40 to 60 (1856-1956), and again few-branch phase (from 1957 onwards) when the number of branches shrank again (from 19 in 1957 to 16 in 1980, 15 in 1989, and 14 in 1993) (Figure 4.3).

A number of branches, once full and mighty, have now vanished (Pivnichny, Shabash, Seredny, Zavodnynsky); other branches have lost part of their flow (e.g. larger Potapivske and Starostambulske Branches, and smaller Belgorodsky and Limba arms). At the same time, other branches (e.g. Starostambulske (outflow) and Bystre) have shown an increase in flow, graphically illustrating the on-going and obvious redistribution of river flow from the Ochakiv system to the Starostambulske system. If not for the continuous dredging of the Belgorodsky Branch mouth and clearing the sandbar in the Prirva Branch mouth, these branches would have died out by the 1950s [4, 5].

Apart from evolutionary changes, the Delta has seen various recurring processes, the most important among them being the upwelling/downwelling events in the estuarine zone and changes in flow discharge rates, both water and sediment, within a year and from year to year. Their major implications primarily relate to fluctuations in water levels in the river arms and wetland areas, and surface deformations affecting the river bed and banks.

Sandbars present in the mouth sections of the delta arms are the most dynamic elements of the delta system. Natural river depths in these areas are rather small, ranging between 2 to 2.5 m even in the most water-abundant arms [6]. The morphology and morphometry of these river mouth sandbars are shaped by many factors, including flow discharge rates for water and sediments, recorded in the river or its arm, various specific characteristics of the maritime estuary (bottom depths and slopes, wave pattern, tidal pattern, upwelling/downwelling events), river ice processes and human activities located in the river mouth and maritime estuary.

The pace of the delta evolution process depends upon the balance between the total sediment flow load carried to the sea via the river arms and its part that is transported further by sea currents. Sediments deposited by the river form the delta, and deltaic floodplains are characterized by a very diverse soil pattern.

The riverbed soil pattern comprises sediments carried with river flow and underlying soil with low scouring/washing potential. In the river section between Reni and Ismail Chatal (160.5 km to 116 km), which is characterized by higher flow velocities, the riverbed soil pattern comprises fine sand (0.1–0.25 mm), while coarser sand (0.25-0.5 mm) is concentrated within the deeper section of the river channel and silty sand is primarily deposited along the riverbanks. Thin sand layer overlies ancient blue-grey clay deposits.

In the river section between Ismail Chatal and Vylkove (116 km to 18 km), the riverbed soil pattern comprises white-grey and yellow-grey ancient clay. Fine sand is carried along by stream current along the bottom of the river channel, and silt builds up along the riverbanks. In the lower section of the delta, river channel and banks are formed by fine silty clay (below 0.01 mm) with sand bands. The river flow moves fine sand along the bottom of the river channel throughout an entire year in the larger arms, and throughout the high-water period only in the smaller arms.

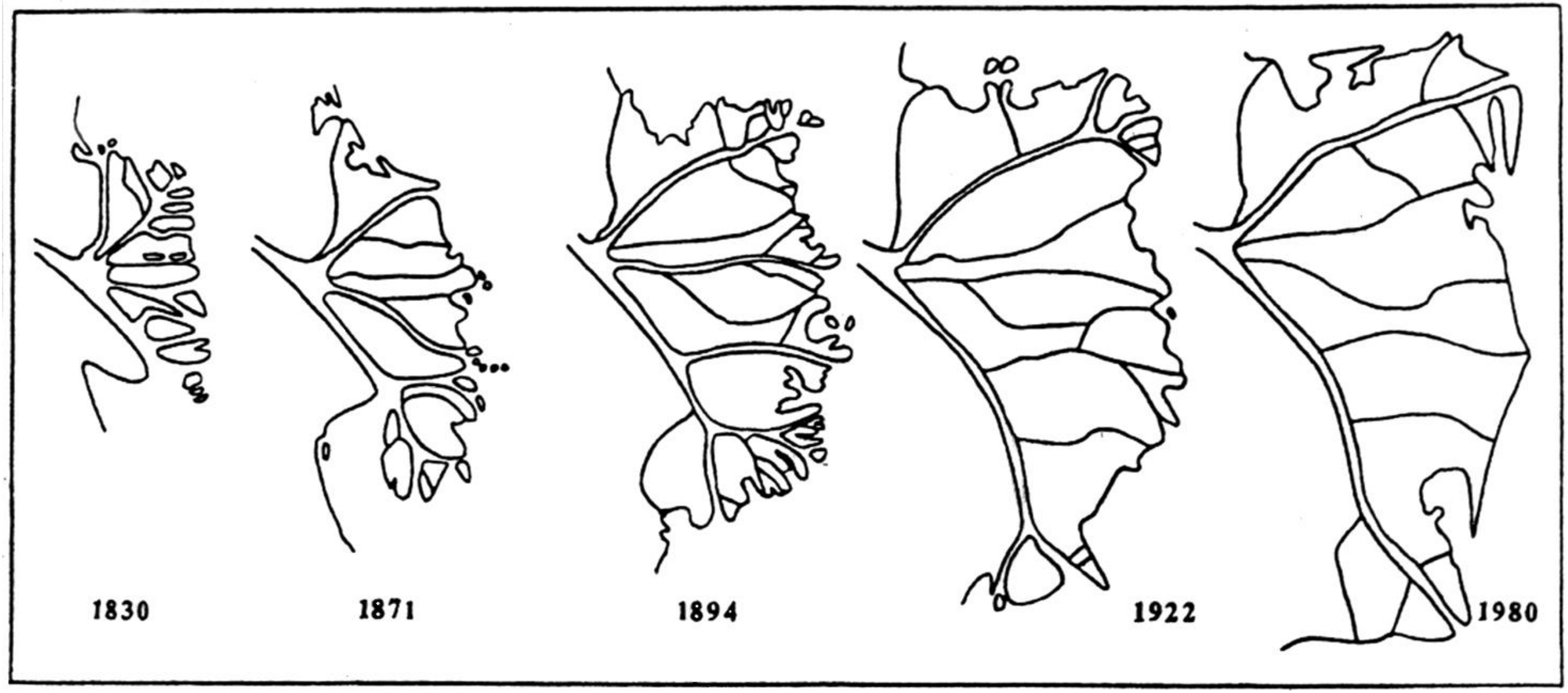

Figure 4.3. Schematic Diagram Illustrating the Evolution of the Chilia Delta

The soil pattern of the delta edge comprises fine to medium sand; sandy loam, both heavy and light; and sandy/loamy silt. In the maritime section of the Chilia delta, the soil distribution pattern is largely aligned along the delta edge.

The sand zone occupies sandbar sections and coastal area extending to the 5 m isobath , though in some locations it extends to the 6 m and even 10 m isobaths, or shrinks to a narrow coastal strip limited by the 1 to 3 m isobaths. In some locations, this zone is 3 to 3.5 km wide. Sand material present in this zone has a relatively uniform grain-size composition, primarily comprising fine and well-graded sand, with medium-size sand occurring in some locations closer to the coast and silty sand with over 5% fraction of silt being deposited further in the sea. The silty sand zone extends along the sea bottom slope, lying at the depths of between 5 m to 7 m and adjoining the sand zone. The silt zone, representing a broad strip, lies at the depths of between 10 m to 25 m.

Hydrological regime and local topography are key factors shaping the soil pattern in the delta. Depending upon the intensity and duration of high-water events, various sections of the Danube Delta may remain flooded or waterlogged for various lengths of time. Rich and diverse plant life represents the main source of humus and nutrients for local soil.

The following five soil types can be identified in the delta: soil present in reed wetlands and floating reed islands; lake/marsh soil; sandy soil; alluvial soil; saline chestnut soil and black earth. Vast areas in the delta remain inundated throughout a year, and soil material is very scarce there. The riparian levees provide the most favourable environment for the development of soil cover, and the most fertile soil is concentrated in these areas.

The climate in the Chilia delta is moderately continental, with the relatively short and mild winters, and long and hot summers. The total duration of no-frost period is over 200 days, and vegetation period lasts for 235-245 days. The effective temperature sum is 3500-3600ºC. The winter typically lasts from mid-December through mid-February, and the spring starts in mid- to late February or early March. The summer starts in early May and lasts till mid-September. The autumn comes in late September or early October.

Mean annual precipitation is 400 mm/year, and mean annual evaporation is 800 mm/year. Mean annual water temperature in the Danube is 12.7°C, and the average duration of the period when water temperature is over 5°C is 265 days (16.03-06.12), over 10°C is 213 days (10.04-09.11), over 15°C is 162 days (04.05-13.10), and over 20°C is 108 days (31.05-16.09).

The abundance of warmth, water and fertile soil promote the development of rich and diverse plant life, including many hydrophilic species present in the wetlands and along the riverbanks. The Danube Delta is particularly rich in reed, being the world’s most dense reed resource. Floating islands, composed of vegetation growing on a buoyant mat consisting of plant roots or other organic detritus, occur in many lakes in the delta.

The delta is home to a wide and diverse range of animal life, including 150 breeding and wintering bird species representing 18 orders [7]. The most common species recorded in the delta are white egret, grey heron, purple heron, squacco heron, cormorant, white pelican, Dalmatian pelican, greylag goose, mute swan, gadwall, coot etc. Mammal species occurring in the delta include wild boar, mink, otter, musk beaver, hare, European wild cat etc.

The delta supports the rich and diverse fauna, providing breeding and spawning habitats for many valuable species, migratory and semi-migratory. The ecological effect of the delta extends far above and beyond its physical footprint. To emphasize and enhance the ecological role of the delta, the Danube Biosphere Reserve (DBR) has been established in the lower section of the Chilia sub-delta.

The DBR represents a varied and unique pattern of ecosystems that reflects the diversity of local landscapes and transitional setting of the delta as an ecotonic system lying between the major river and the Black Sea. A mix of natural, geological and anthropogenic factors have steered the development of a unique Zhebiryanska Range ecosystem that comprises what remains of the natural sand steppe and Crimean pine plantation. The ecosystem of the Zhebriyansky Spit can be classified as sandy/littoral.

The major part of the Chilia delta, including the Stentsivsky/Zhebriyansky wetlands and (partially) Yermakiv Island, is occupied by wetland ecosystems dominated by the reed/narrow-leaved cat's tail/common tule/scirpuslike sedge communities. Pussy willow thickets are scattered in the area like spots.

Forest and shrub communities present in the wetland areas of the Danube Biosphere Reserve comprise both natural and man-made plantations. Tree/shrub thickets extending along the banks of watercourses in the form of strip with the width ranging between 5 to 200 m comprise white willow, crack willow, and almond-leaved willow. Trees and bushes growing along the coastal line comprise silverberry, indigo, tamarisk and sea-buckthorn.

Meadow ecosystems occupy elevated areas, riparian levees and wetland edges lying along the coastal dunes. These ecosystems replace marsh and riparian/aquatic communities as they disappear due to the progressive surface elevation caused by the build-up of alluvium. The meadow plant communities are largely dominated by large-grain cereals, fine-grain cereals, reed species, rush species, and species typical of the motley grass saline meadows. Meadows occupy a significant part of the Yermakiv Island.

Aquatic ecosystems present within the boundaries of the Danube Biosphere Reserve are mainly of freshwater type, with the brackish-water ecosystems developing in the numerous small streams, lagoons and lakes concentrated in the outer delta of the Chilia Branch. A contact zone providing interface between the Danube and the Black Sea supports a highly specific maritime estuarine ecosystem. Apart from suspended solids and dissolved nutrients, the river flow emptied into the sea via this zone also contains freshwater plankton and other organisms whose annual load ranges between 100,000 to 200,000 tonnes. As this living matter dies off, it is deposited on the bottom to create the stock of organic matter. This process plays a decisive role in shaping the biological productivity in the north-western part of the Black Sea itself, thereby providing food stocks for valuable migratory fish species present in the Danube (especially sturgeon and Danube shad species).

Plant life supported in the Danube Biosphere Reserve (DBR) comprises 950 vascular plants relating to 379 genera and 100 families. Of that, 134 plant species (14.1%) are classified as rare and/or endangered species, with 16 species included into the Red Data Book of Ukraine, and 3 species included into the European Red List. As can be seen on the schematic maps presented in Figures 4.4 and 4.5) [8], the major proportion of rare and endangered species is concentrated in the area of the Zhebriyansky Range and along the most southward edge of the DBR site, whereas only 2 rare and 2 endangered species have been recorded in the Bystre Branch area, being also widely distributed the entire core area of the reserve.

According to [5], the Ukrainian part of the Danube Delta is home to 95 fish species representing 31 families. The freshwater fish community is dominated by the Cyprinidae, Percidae, and Gobiidae species. It also includes all fish species from the European Red List (e.g. spiny sturgeon and Baltic sturgeon from the Acipenseridae family, Black Sea salmon and Danube Salmon from the Salmonidae family; chop and little chop from the Percidae family, and European mudminnow. These and other 8 fish species are included in the Red Data Book of Ukraine.

The Danube remains the only river in the Black Sea Basin where the migratory sturgeon species spawn naturally. The major part of sturgeon's spawning habitats is outside the Ukrainian boundaries. The Danube within Ukraine is the main migratory route for spawning individuals and larvae, and the outer delta also provides an important breeding habitat for juveniles. According to [9], the total area of breeding habitats used by the migratory sturgeon species in the Ukrainian part of the Danube Delta and extending along the 5-km coastal zone is 16,250 ha. Another species that ranks second in terms of commercial value, and first in terms of landings (56.1%) is the Black Sea (Danube) shad, which is a typical migratory species with its spawning areas located outside the Ukrainian part of the Danube Delta.

Figure 4.4. Schematic Map Showing the Distribution of Vascular Plants Included into the Red Data Book of Ukraine over the Territory of the Danube Biosphere Reserve

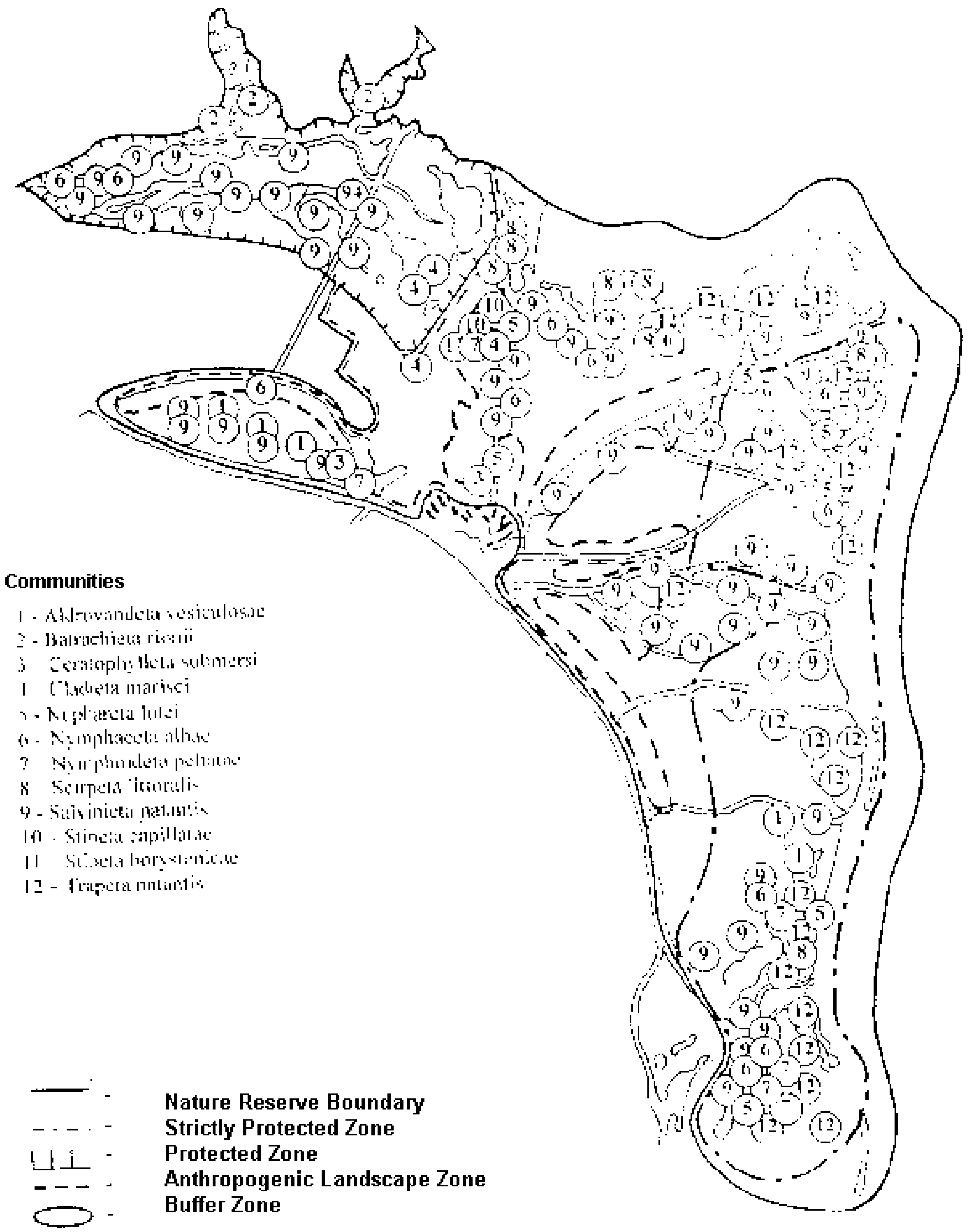

Figure 4.5. Schematic Map Showing the Distribution of Plant Communities Included into the Green Data Book of Ukraine over the Territory of the Danube Biosphere Reserve

The territory of the Danube Biosphere Reserve is home to many amphibian, reptilian and mammal species that enjoy special protection status at the national and international level. It should be noted that this area has a large share of the population of many species that are on the verge of extinction in many European countries.

The Chilia sub-delta is an internationally significant wetland area, especially for its varied habitats supporting a wide range of bird life that comprises about 257 bird species (or 62% of Ukraine's bird species diversity), including 124 species that use the Danube Delta for nesting. Migratory birds constitute the largest group consisting of 196 species (129 wintering species, 41 summering species, 3 nomadic species, and 8 visiting species). There are 42 bird species that are included in the Red Data Book of Ukraine and the European Red List [5]. Since 1975, the Chilia sub-delta wetlands have been included in the Ramsar List of Wetlands of International Importance, and this special status was confirmed in 1996 at the Meeting of the Conference of the Contracting Parties to the Ramsar Convention signed in 1971. There is broad and common recognition of the unique nature and ecological value of many bird communities present in the Danube Delta and its vital role for the conservation and restoration of many vulnerable species.

The overwhelming majority of bird species known to occur in the territory of the Danube Biosphere Reserve enjoy a special protection status under various international environmental conventions and treaties. The 1994 Red Data Book of Ukraine and the 1991 European Red List comprise 42 bird species, or about 16% of the total number of species recorded in the DBR area, including 11 nesting species, 31 transiting species, 22 wintering species, 16 summering species, and 2 visiting species. The following species recorded in the study area have been included in the IUCN Red Data Book: Dalmatian pelican (*Pelecanus crispus*), pigmy cormorant (*Phalacrocorax pigmaeus*), red-breasted goose (*Rufibrenta ruficollis*), white-tailed eagle (*Haliaeetus albicilla*) etc.

Especially spectacular are waterfowl and riparian bird communities, including Anseriformes (swan, goose, duck), Pelecaniformes (pelican, cormorant), Ciconiiformes (egret, ibis), Charadriiformes (sandpiper, gull). Many of these species are from the Red Data Book of Ukraine, including white pelican (*Pelecanus onocrotalus*), spoonbill (*Platalea leucorodia*), glossy ibis (*Plegadis falcinellus*), squacco heron (*Ardeola ralloides*), ferruginous duck (*Aythya nyroca*), black-winged stilt (*Himantopus himantopus)*, greenshank (*Tringa nebularia*) and other [5]. The Danube Delta is home to most of the world's population of pygmy cormorant, and also has a large share of the European population of the Dalmatian pelican.

In terms of bird species diversity, the secondary Chilia Branch sub-delta ranks first among the four main parts of the Danube Biosphere Reserve, followed by the Stentsivsky/Zhebriyansky wetland area, Zhebriyansky Range, and Yermakiv Island. This area is home to the main Delta's colonies of cormorants, egrets and ibises. Vast and spacious shallow maritime areas of the outer Chilia sub-delta play especially important role in supporting waterfowl and riparian bird life. Depending upon season, this area may host as many as over 50,000 birds. It provides habitat for the majority of migrating ducks, including mallard whose seasonal population can be as large as 16,000–20,000 individuals, and the population of coot is comparable in size. Mute swan population that uses the southern silted section of the maritime delta as a moulting place may range in various years from 500 to 5,000 individuals.

Especially valuable are bird communities associated with the coastal flat islands and spits. For example, the Ptashyna Spit emerged south of the Bystre Branch mouth in the late 20th century, to provide habitat for one of the two DBR's most significant colonies of Charadriiform species, including oystercatcher (Red Data Book of Ukraine), snowy plover (Red Data Book of Ukraine), common tern, sandwich tern, yellow-legged gull, and avocet. The detailed description of existing environment and key environmental features present in the project area can be found in the EIA

Report that forms part of the Detailed Design Documentation for the Full-Scale Project (Sections 2, 4.1.1, 4.1.3, 4.3.1– 4.3.3, 4.4, and 4.5) [1].

The volatile and variable character of natural factors is the main cause (and outcome) of the delta evolution process, and this variability affects both natural and technogenic features present in the area. The history and experience of the Danube shipping graphically illustrate that environmental effects associated with the construction and operation of navigation routes occur and arise in the context of definitive impacts caused by delta development processes that are evolutionary and cyclic in nature, and the latter may either exacerbate or weaken the former. In assessing potential environmental impacts of the proposed navigation route, one should disentangle the consequences caused by the route development from those of inherent variability of natural factors.

In order to enable the identification of the most significant environmental factors that are of direct relevance to the proposed activity, these factors were considered in the context of their interactions with anthropogenic factors associated with the proposed activity (Table 4.3). In addition to those environmental factors that either affect the proposed activity or are susceptible to impacts thereof, the site selection process should also include a review of those factors that are capable of exacerbating or minimizing adverse effects of anthropogenic factors. More specifically, the fact that the selected option of the Danube-Black Sea Navigation Route runs along the natural deep branches of the Danube Delta (environmental factor) has helped minimize land withdrawal and dredging requirement (impact factor). It should be noted that land withdrawal and dredging are considered to be the most significant adverse aspects of all ship navigation schemes operated/planned in the Danube Delta.

Table 4.3. Key Types of Interactions between the Environmental Factors and Anthropogenic Factors Associated with the Proposed Activity

No.	Type of Interaction	Example
1	Environmental factors affect proposed activity	Sediment transport with river flow causes siltation and impedes navigation
2	Change/modification of environmental factors due to proposed activity	River channel canalization helps increase flow velocity and reduce/minimize siltation
3	Environmental factors and anthropogenic factors add up	Solids re-suspended in water as a result of dredging add up and complement the natural sediment flow
4	Environmental factors change/modify the intensity of impacts associated with proposed activity	A sandbar present in the mouth section of the branch leads to a greater dredging effort required to establish and operate the navigation route

The Tables 4.4 and 4.5 below summarise and describe potential environmental consequences that may be associated with the development and operation of navigation route in the Danube Delta. These tables are based on the analysis of impacts undertaken as part of the EIA process for the full-scale project.

Table 4.4. Overview of Environmental Consequences of the Project

Impact-shaping Processes	**Potential Environmental Consequences**
I	Reduced primary productivity of benthic species. Damage to fish fauna due to the loss of food stocks. *Area of impact: the NR sections affected by factors 1.1, 1.2, 2.1, 2.2*.
II	Increased intensity of sediment redistribution processes. Modified flow distribution pattern. *Area of impact: the system of delta branches.*
III	Soil degradation and resultant damage to flora and fauna. *Area of impact: dredging dumpsites.*
IV	Deterioration of water quality, increase in trophic level, deterioration of oxygen regime in the locations of dredging activities and adjacent downstream section, potential for toxic effects on aquatic biota; reduced phytoplankton and phytobenthos productivity in the areas with elevated turbidity levels. Damage to fish fauna due to the loss of food stocks and potential toxic effects. *Area of impact: sections of delta branches downstream of dredging locations.*
V	Deterioration of water quality, increase in trophic level, deterioration of oxygen regime in the coastal zone of the sea, potential for toxic effects on aquatic biota; reduced phytoplankton and phytobenthos productivity in the areas with elevated turbidity levels. Damage to fish fauna due to the loss of food stocks and potential toxic effects. *Area of impact: adjacent part of marine delta.*
VI	Deterioration of surface water and groundwater quality. *Area of impact: coastal area.* Increase in trophic level and deterioration of oxygen regime downstream of dumpsites, potential for toxic effects on aquatic biota. *Area of impact: sections of delta branches downstream of dumpsites.*
VII	Deterioration in living conditions and disturbance to local fauna. *Area of impact: riparian areas along the navigation route, areas adjacent to the locations of operational dredges and other project machinery.*
VIII	Deterioration in living conditions for local population, and deterioration of local flora/fauna habitats. *Area of impact: areas adjacent to the locations of operational dredges and other machinery, riparian areas along the route.*
IX	Potential loss of safe nesting habitats for protected bird species, disturbance/modification of fish spawning/feeding areas. *Area of impact: coastal sections of delta.*
X	Potential for degradation of existing and development of new benthic communities. Departure of some rare and endemic fish species. *Area of impact: the mouth section of river branch as it joins the estuary*
XI	Increased species diversity and benthic biomass due to the development of biofouling communities. *Area of impact: flow management structures and rock/gravel filled dams.*
XII	Increased intensity of water exchange and variations in water levels along the shorelines. *Area of impact: shoreline sections of river channel*
XIII	Changes in water regime of wetland areas. Loss of habitats for ecotone, valuable and protected fauna species. *Area of impact: riverbank levees and adjacent wetland sections.*
XIV	Deterioration of water quality and oxygen regime, potential for toxic effects on aquatic and riparian species. *Area of impact: river sections downstream of an accident/spill site; adjacent parts of the estuary and coastal area – in the event of a major accident/spill.*
XV	Potential undesirable change in the aquatic and terrestrial ecosystem structure, displacement of protected and valuable species, deterioration of parasitological status. *Area of impact: river channel and riparian wetlands.*

Table 4.5. Medium-Specific List of Potential Environmental Consequences of Project Impacts

Environmental Medium	Potential Environmental Consequences
Geology	- Modification/change in the bottom and riverbank topography; - Increased intensity of sediment redistribution processes; - Redistribution of sediment load carried with river flow among the branches; - Riverbank erosion in some areas along the navigation route due to the impact of waves induced by ship traffic; - Change in water regime of Delta's islands; - Change in the Delta evolution process.
Water	- Increase in flow discharged through those Delta branches that form the navigation route; - Change in flow velocity pattern in the sandbar section of the navigation route, - Upward invasion of marine waters into the branch; - Alteration of ecological conditions in some sections due to the emergence of solid substrates; - Temporary decrease in the self-purifying capacity of the river ecosystem; deterioration of water quality and oxygen regime in the locations of dredging activities and downstream, in the surrounding areas of the sea adjacent to the offshore dumpsite, and downstream of a ship accident (in the event of a ship accident); - Deterioration of groundwater and surface water quality in the locations of dredging dumpsites.
Air	- Noise and gaseous/aerosol emissions of harmful substances from ship engines, construction machinery and auxiliary vessels, and in the event of an accident involving fire or explosion at a passing ship (stationary sources of air pollution are none, both for construction and operation phases).
Soil	- Change in soil properties at the sites used to dump/dispose of dredged bottom sediments.
Biota	- Destruction/loss of benthic organisms at the dredging/dumping locations, with their subsequent restoration; - Impairment and partial loss of plankton biota in the areas adjacent to dredging and dumping sites; - Decrease in primary productivity of benthic organisms due to an increase in average water depths along the navigation route; - Alteration of benthic species composition in the sections affected by saline water invasion and where the gravel material would be emplaced; - Shrinkage of food stocks for fish and loss of some spawning areas; - Modified/reshaped vegetation cover at the riparian dumpsites for dredged bottom sediments; - Scaring effect and disturbance to birds and terrestrial animals living in the adjacent areas.

4.3. Multi-Criteria Comparison of Navigation Route Options in Terms of Their Relative Environmental Safety that Uses the Analytical Hierarchy Process (AHP) and Takes Account of Transboundary Aspects

The multi-criteria comparison of various navigation route options was undertaken using a combined (verbal and formal) decision-making technique that employs the analytical hierarchy process (AHP) developed by Thomas L. Saaty [10-15]. The essence of the AHP method is that a complex decision problem is first decomposed into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. Once the hierarchy is built, the decision makers systematically evaluate its various elements, comparing them to one another in pairs. In making the comparisons, the decision makers can use concrete data about the elements, or they can use their judgments about the elements' relative meaning and importance. The AHP method converts these evaluations to numerical values.

The analytical hierarchy process enables the use of both concrete measurable data and expert judgments to make decisions on complex problems where important elements of the decision are difficult to quantify and compare. The method draws on the theory of matrices and employs a suite of expert evaluation procedures that help capture and consider all available information that is of relevance to the elements of the decision.

An AHP hierarchy is a structured means of describing the problem at hand. It consists of an overall *goal*, a group of options or *alternatives* for reaching the goal, and a group of factors or *criteria* that relate the alternatives to the goal. In most cases the criteria are further broken down into subcriteria, sub-subcriteria, and so on, in as many levels as the problem requires. The hierarchy can be visualized as a diagram with the goal at the top, the alternatives at the bottom, and the criteria filling up the middle. To incorporate their judgments about the various elements in the hierarchy, decision makers compare the elements two by two.

The matrix building procedure is described below.

If $A_1, A_2, A_3,..., A_{ij}$ constitute a set comprising n elements, and $w_1, w_2, w_3,... w_n$ are relative weights reflecting their preference, the weight (or priority) of an element can be compared with that of another element in order to establish their relative importance and contribution to their common parent goal (Table 4.6).

Table 4.6. Evaluating Relative Significance/Priority of Elements within Each Group A

Goal	A_1	A_2	A_3	...	A_n
A_1	$\frac{w_1}{w_1}$	$\frac{w_1}{w_2}$	$\frac{w_1}{w_3}$	...	$\frac{w_1}{w_n}$
A_2	$\frac{w_2}{w_1}$	$\frac{w_2}{w_2}$	$\frac{w_2}{w_3}$	...	$\frac{w_2}{w_n}$
A_3	$\frac{w_3}{w_1}$	$\frac{w_3}{w_2}$	$\frac{w_3}{w_3}$	...	$\frac{w_3}{w_n}$
:	:	:	:	:	:
A_n	$\frac{w_n}{w_1}$	$\frac{w_n}{w_2}$	$\frac{w_n}{w_3}$	...	$\frac{w_n}{w_n}$

The results of comparisons made in the Table 4.6 can be presented in the form of a square and reversely symmetrical matrix of judgments:

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} & \dots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \dots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \dots & a_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & a_{n3} & \dots & a_{nn} \end{pmatrix} \qquad (4.3.1)$$

In an abridged form, the matrix (4.3.1) can be presented as follows:

$$A = \{a_{ij}\}$$

Indices i and j refer, respectively, to the line and column where the a_{ij} element is located. In a square matrix of the n order, the number of lines (m) equals to the number of columns (n).

With $m = n$

$$A = \{ a_{ij} \}_{n,\, n} \qquad (4.3.2)$$

$$a_{ij} = 1; \qquad a_{ij} = \frac{1}{a_{ji}}, \text{ where } i = \overline{1, n}\ ;\ j = \overline{1, n}$$

with $i=j$;

The next step is to define the vector w=[w_1, w_2,..., w_n]. The AHP hierarchy can be visualized as a diagram where the goal or criterion is at the top, and the options compared are listed from left to right, and from top to bottom. At each level of hierarchy, a matrix of pairwise comparisons is built for each group of options to be compared with respect to the covering criterion of the group (which the node lying directly above these options in the hierarchy).

Each pair of items in the i-th row is compared regarding their importance with respect to each element j –in the (i-1) row. In each row, the n number of matrices is to be defined where n is the number of elements or nodes in the above row. The pairwise comparison is the process designed to establish which element or criterion in the group is more important with respect to the covering criterion of the group (intermediate goal). If the values or measurements for w_1, w_2, w_3,... w_n cannot be stated with absolute certainty, each pair of elements is compared using verbal judgments that describe their relative importance and can be converted into numbers or priorities with the help of priority scale presented in Table 4.7.

Table 4.7. Relative Importance of Elements (by Saaty)

Measure of Relative Importance	**Judgment**	**Explanation**
1	Equal importance	Two elements contribute equally to the goal
3	Moderate importance	Experience and judgment slightly favour one element over the other
5	Strong importance	Experience and judgment strongly favour one element over the other
7	Very strong importance	One element is favoured very strongly over the other; its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one element over another is of highest possible order of affirmation
2, 4, 6, 8		Intermediate values

The AHP method addresses the issue of ensuring the internal consistency of judgments by employing the eigenvector (priority vector) and eigenvalue $\lambda_{\max}$. The following matrix equation is to be solved for each matrix:

$$Aw = \lambda_{\max} w \qquad (2.3)$$

This equation is solved by exponentiating the matrix A to higher power, with subsequent row summation and normalization (dividing the sum of each row by the sum of all elements within a matrix), to derive the priority vector $w = (w_1, ,\ldots\ w_n)^T$. The calculation process is over when the difference between the components of priority vectors derived for the matrix A at the k-th and (k+1)-th power is smaller than a specified precision rate. The relative weights or priorities given to the elements at a given hierarchy level reflect their relative ability to achieve an intermediate goal which the node directly above them in the hierarchy.

The eigenvalue $\lambda_{\max}$ is calculated by summing up each column in the pairwise comparison matrix and multiplying the resultant vector and normalized priority vector.

Once all elements have been compared and the eigenvalue calculated, the consistency of responses within the matrix is to be checked by producing the consistency coefficient (CC):

$$\mathrm{CC} = (\lambda_{\max} - n)/(n - 1),$$

$$\lambda_{\max} = \geq n,$$

where n is the number of elements (factors) compared (the order of the matrix).

The CC coefficient is then compared with the mean consistency (MC) values produced for a random matrix of the same order. This comparison can made using values presented in Table 4.8.

Table 4.8. Mean Consistency Values Adopted for Random Matrices of Various Order

Matrix dimension	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Random consistency index	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The consistency ratio (CR) can be calculated as follows:

$$\boldsymbol{CR = \frac{CC}{MC} \cdot 100\%}$$

The consistency is considered acceptable when the CR is about 10%, reaching up to 20% in some occasions. Any other percentages would mean that the internal consistency of judgments is not acceptable and all judgments that have been entered would need to be checked.

The next step involves the synthesis of numerous judgments about the problem where local priorities for each group at each level are known, as are the relative contributions of each criterion to the priority of the goal. Based on this, the global priority of each factor considered in the hierarchy can be calculated, to be further used as a weight required to calculate local priorities at the next lower level. In the end, the AHP method arranges and totals the global priorities for each of the alternatives.

Criteria and factors employed in the comprehensive comparative assessment of environmental impacts associated with various navigation route options are summarized and presented in Tables 4.9and 4.10.

Table 4.9. Ranking Scale for Defining the Relative Significance of Impacts

No.	Measure of Significance	Explanation
1	Minor	Minor scale/severity of impact factors. Small area of impact. Reversible impact. No change in natural processes and ecosystem characteristics
2	Within permissible levels	Estimates and calculations indicate that existing environmental standards will be complied with
3	Acceptable	Minor and short-term impact. Small area of impact. Effects are reversible or cause no deterioration in the ecosystem status in terms of the whole range of indicators
4	Conditionally acceptable	An impact can be minimized/reduced to meet the permissible levels or to become acceptable through the implementation of specified mitigation measures
5	Compensable	Irreversible effects can be compensated through the implementation of environmental improvement measures beyond the area of impact of proposed activity but still within the boundaries of the affected natural system
6	Local	Consequences are manifested in episodic facts of non-compliance with existing environmental quality standards that affect only a limited area, cannot be fully avoided/prevented by mitigation measures and are not able to be fully compensated
7	Considerable	Intermediate value
8	Significant	Frequent and detectable exceedances of existing standards across a vast area, partially mitigable and/or compensable. Can be considered as acceptable based on the results of a comprehensive environmental/economic feasibility study
9	Unacceptable	Frequent exceedances of existing standards across a vast area, inevitably causing the degradation of ecosystem that cannot be justified by any economic gains

Table 4.10. Parameters Used to Assess Relative Significance of Transboundary Impacts

No.	Impact Parameter	Parameter Description
1	Impacted area	The extent of an area that is within the jurisdiction of an affected party and is likely to be impacted by the proposed activity
2	Ecological value of impacted area	Characterisation of ecological value of the area that is likely to be affected (including any protected areas)
3	Key impacts	List of key impact factors associated with the proposed activity
4	Key environmental factors/receptors	List of environmental factors that are likely to be most affected by the impact
5	Variations under the Status-Quo scenario	Variations in the characteristics of key factors in the absence of the proposed activity
6	Level of variation	What is the likely margin of change relative to the existing status and values of parameters considered
7	Likelihood	What is the likelihood of potential impact? Is it likely that the impact may occur under the normal operation conditions or in the event of emergency or accident
8	Duration	Is the impact of temporary, short-term or long-term duration? Is it likely to occur during construction, operation or closure
9	Recurrence	Is the impact likely to occur on repeated occasions
10	Reversibility	Is it likely that the impact can be reversed.

Figures 4.6 and 4.7 show the flow charts illustrating the decision-making process underpinning the selection of the best practicable environmental option and multi-criteria assessment of environmental impacts that may be associated with major water engineering projects, featuring the use of the Analytical Hierarchy Process (AHP) developed by Thomas L. Saati.

The ultimate objective of this multi-criteria assessment is to select the most appropriate and environmentally safe option of the navigation route, to meet all relevant technical standards set for deep-water shipping routes. To meet this objective, the Analytical Hierarchy Process (AHP) as proposed by T. Saati has been adjusted/modified to suite the specific needs of the present study.

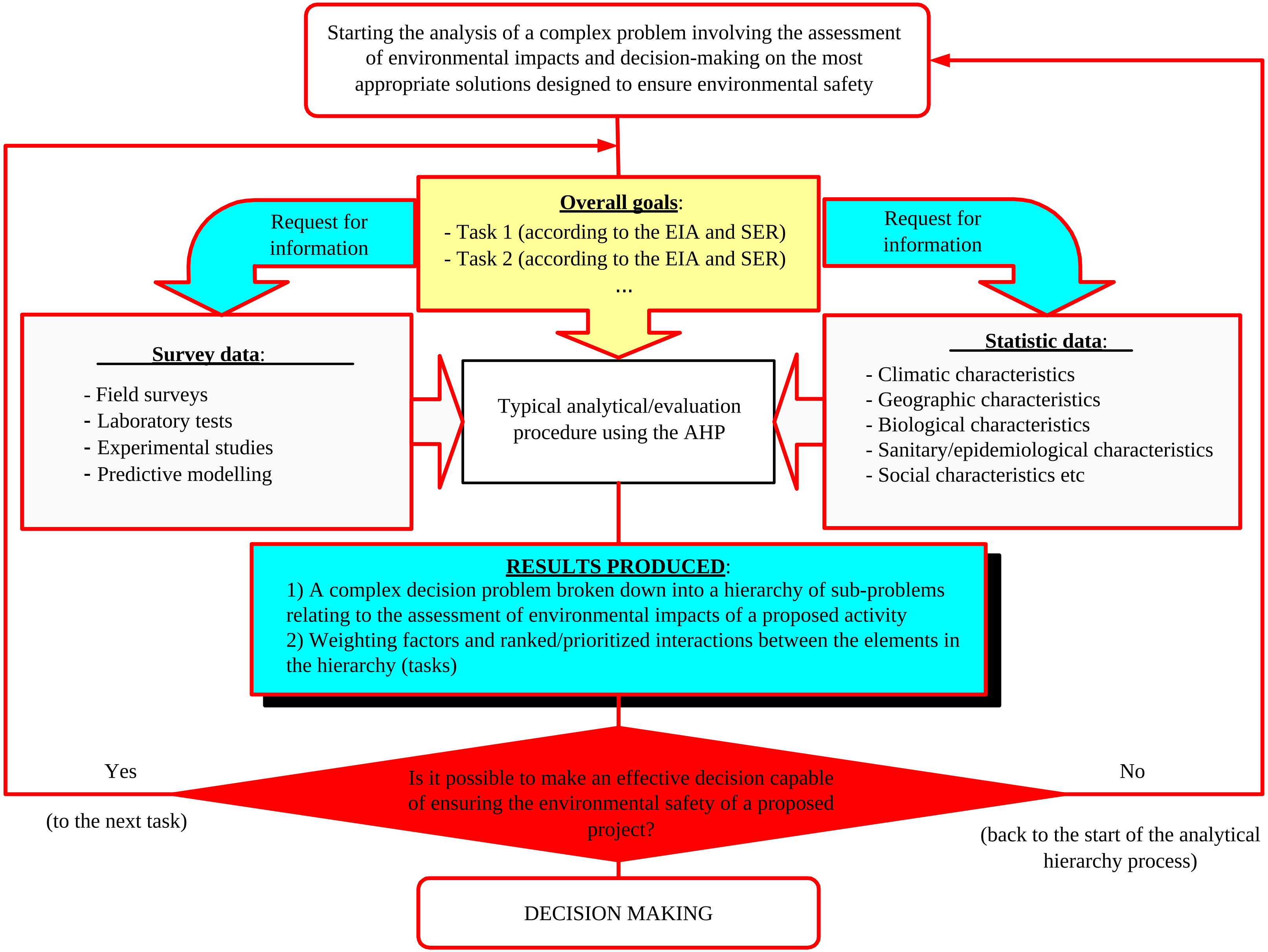

Figure 4.6. Decision Making Process Flowchart

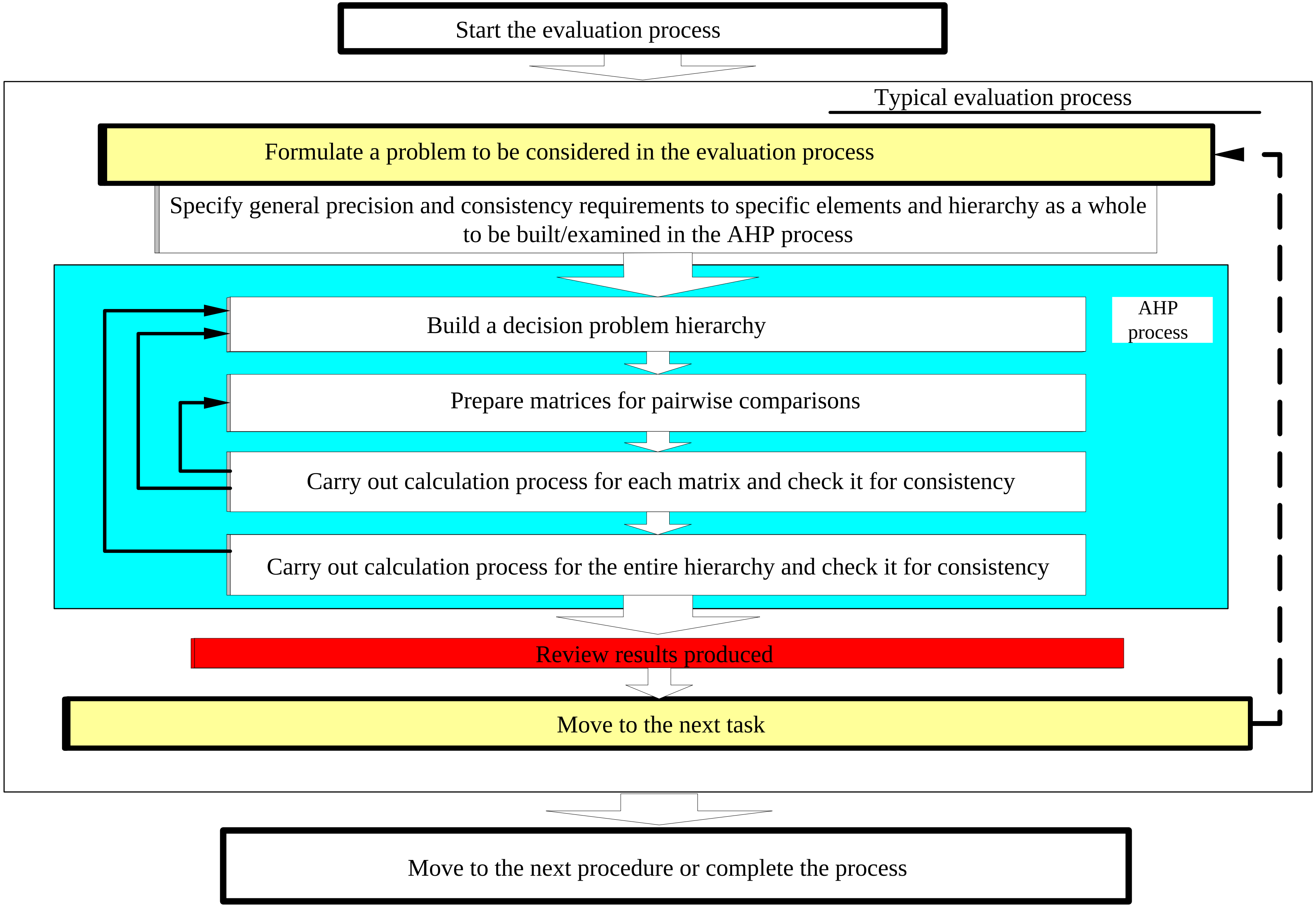

Figure 4.7. Process Flowchart: Comprehensive Environmental Impact Assessment Process Based on the AHP Method

An AHP hierarchy is a structured means of describing the problem at hand as an overall goal with a group of options or alternatives for achieving that goal, and a group of factors or sub-criteria (SC) that relate the alternatives to the goal defined as the environmentally safe navigation route: technical aspects (SC-1), environmental requirements (SC-2), and transboundary aspects (SC-3).

The third level comprises specific criteria (C1÷C6) that define various specific aspects of sub-criteria defined at the second level of the hierarchy.

The fourth level comprises environmental parameters (factors) and technical parameters (P1÷P10) that are associated with the criteria.

The fifth level reflects impact factors (F1÷F6) shaped by the environmental and technical parameters that are directly linked to them.

The sixth level specifies six alternative options of the navigation route (A1÷A6) from those presented in Table 3.2 (i.e. those that are linked to the Chilia Branch). All these options are considered to meet current international technical standards set for deep international waterways. Among these options, the one that comes close to the ‘zero’ scenario as defined in the Section 3 (Item 6 in Table 3.2) is Option A.3 (Item 7 in Table 3.2). The main difference between the latter and the ‘zero’ scenario relates to larger depths and higher technical safety standards.

Once all the elements in the hierarchy have been defined, the next step is to establish and define links connecting the interdependent elements at various hierarchical levels. In this way, the hierarchy constructed will represent a coherent system comprising goal, criteria, sub-criteria, parameters, factors and alternatives.

The assessment procedure is summarized below. The first step is the development of the matrix of preferences at the sub-criteria level using the Saaty’s scale scores. The order of the matrix, based on the number of sub-criteria, is 3. By analyzing this matrix, decision-makers are able to define local preferences at the sub-criteria level and evaluate the relative consistency of the matrix. If the relative consistency is acceptable (up to 10%), the procedure moves to the second step, where the matrices of preferences are defined for all criteria outlined on the third level relative to the sub-criteria specified on the second level. The number of matrices, based on the number of sub-criteria, is 3. The order of each matrix is defined as the number of links connecting the criteria with sub-criteria (n = 3 for the first matrix, n = 4 for the second matrix, and n = 2 for the third matrix).

The matrices are evaluated to produce local priorities on the criteria level and ensure that there is the consistency of the responses, and the process moves on the next stage. Further stages involve the development and evaluation of matrices of judgments, where local priorities are produced on the third through sixth levels of the hierarchy, matrices are checked for consistency and judgments are clarified if and where needed.

The decomposition of the complex problem that can be formulated as a comprehensive environmental safety assessment of the proposed Danube-Black Sea Navigation Route is presented in Figure 4.8.

The decomposition procedure is followed by the synthesis procedure that involves the identification of global priorities on each level (Figures 4.9 to 4.13) and for the entire hierarchy (Figure 4.14). Also, the relative consistency of the entire hierarchy has been evaluated (8.6%).

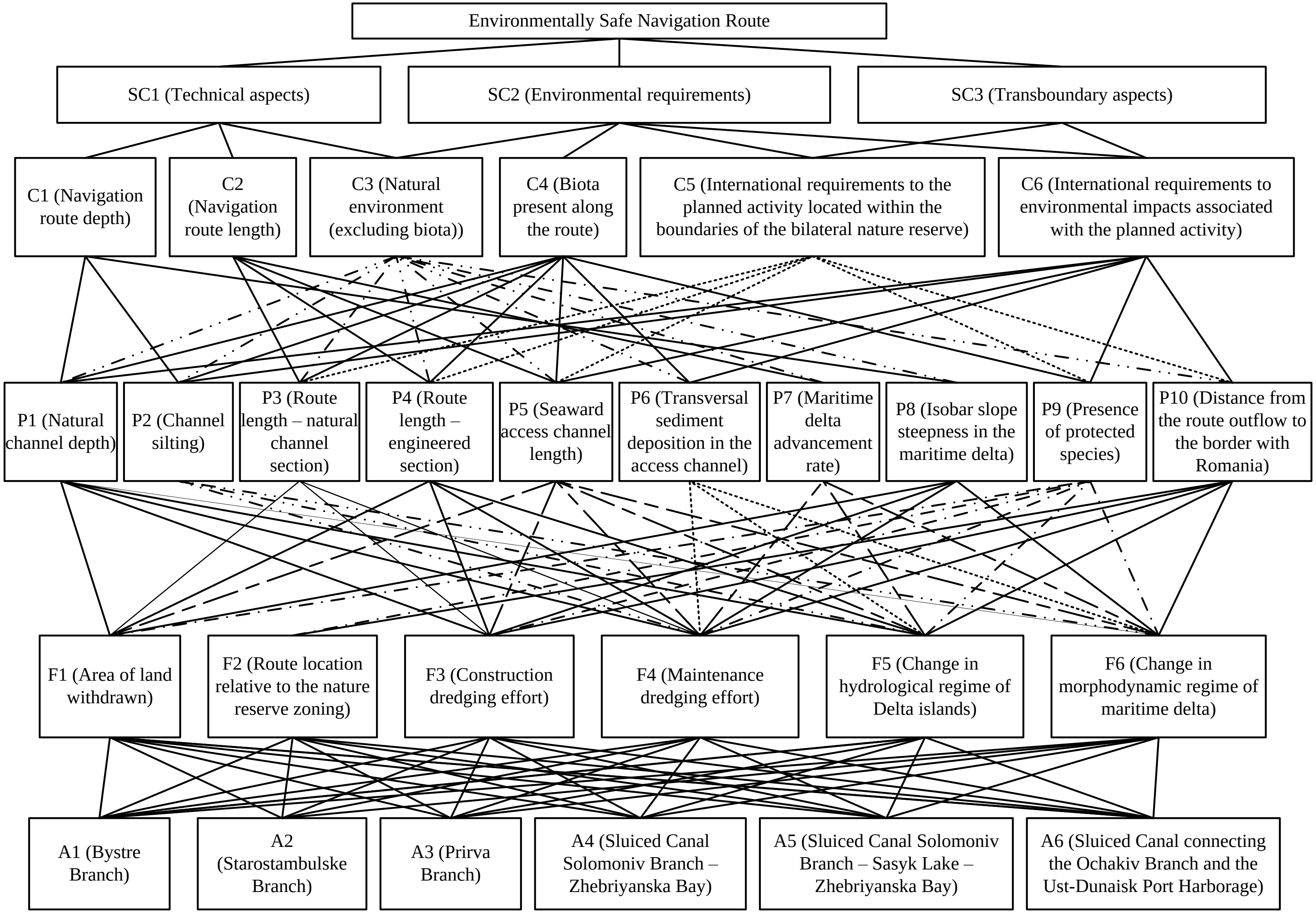

Figure 4.8. Decomposition of the Complex Problem (Selection of the Best Environmentally Safe Option for the Development of the Danube-Black Sea Navigation Route Based on the Multi-Criteria Environmental Impact Assessment)

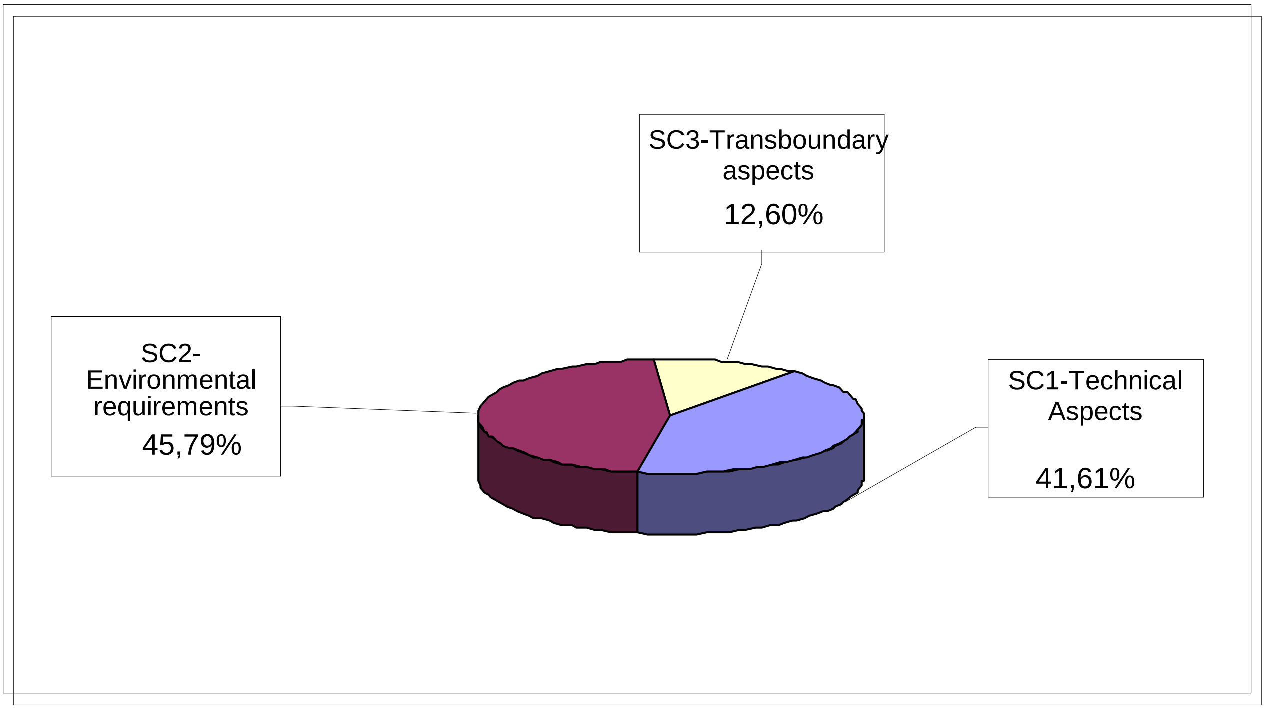

Figure 4.9. Distribution of Priorities among Sub-Criteria SC1...SC3

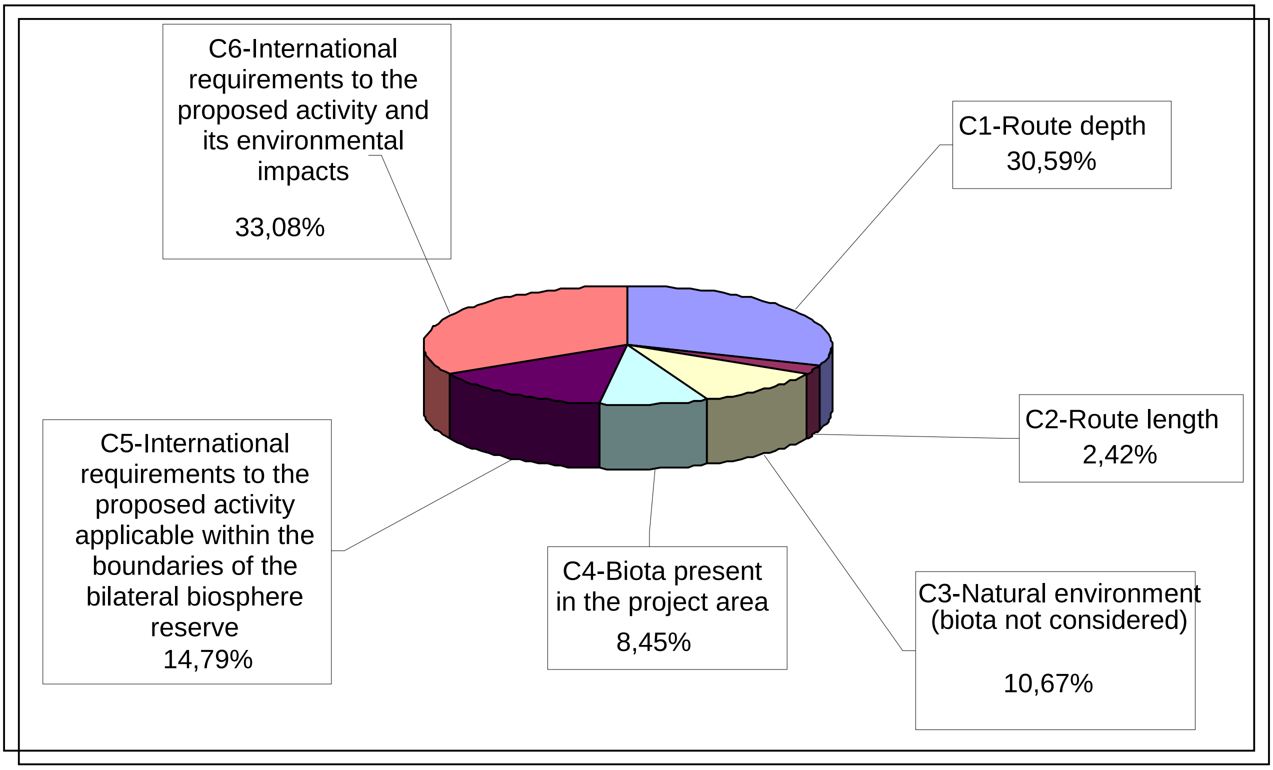

Figure 4.10. Distribution of Priorities among Criteria C1...C6

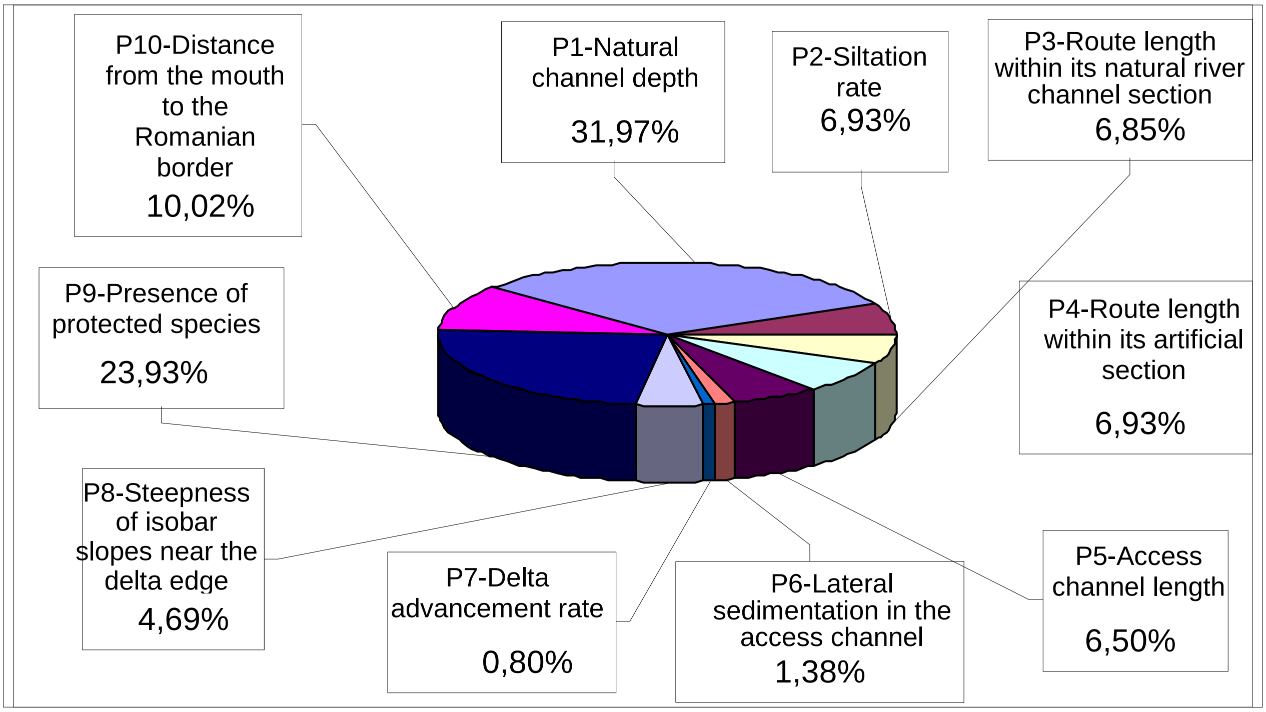

Figure 4.11. Distribution of Priorities among Parameters P1...P10

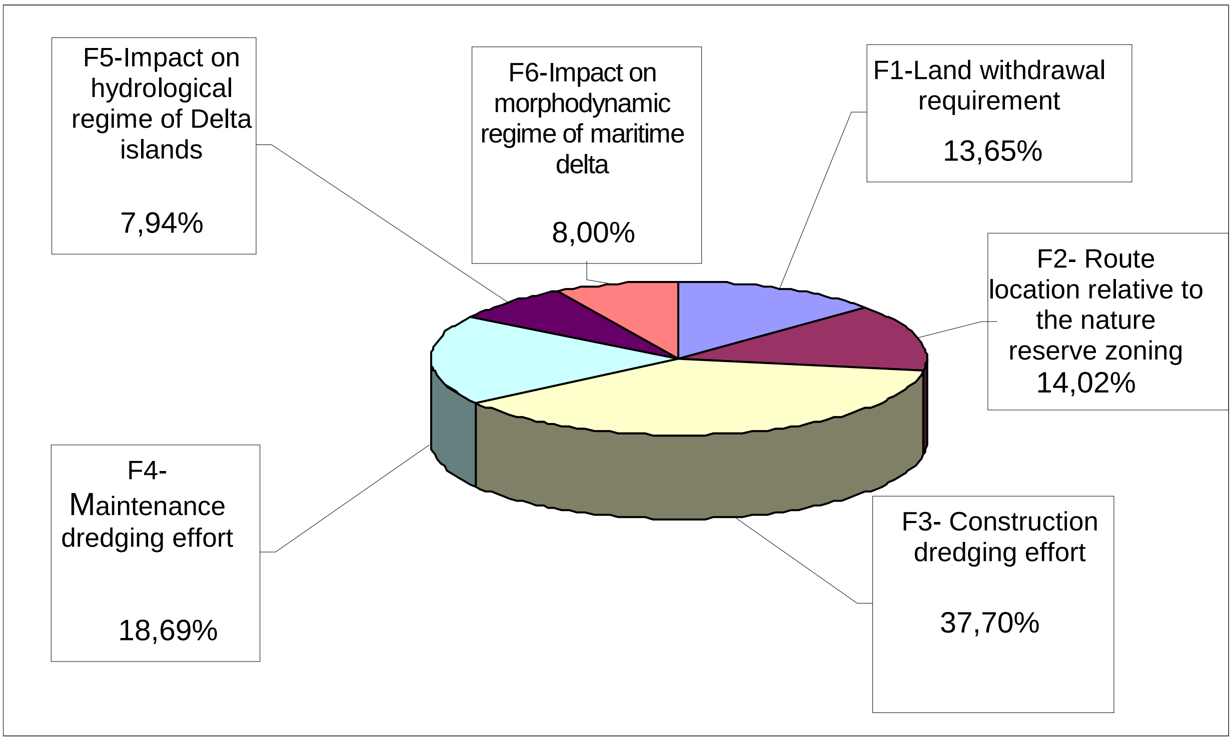

Figure 4.12. Distribution of Priorities among Impact Factors F1...F6

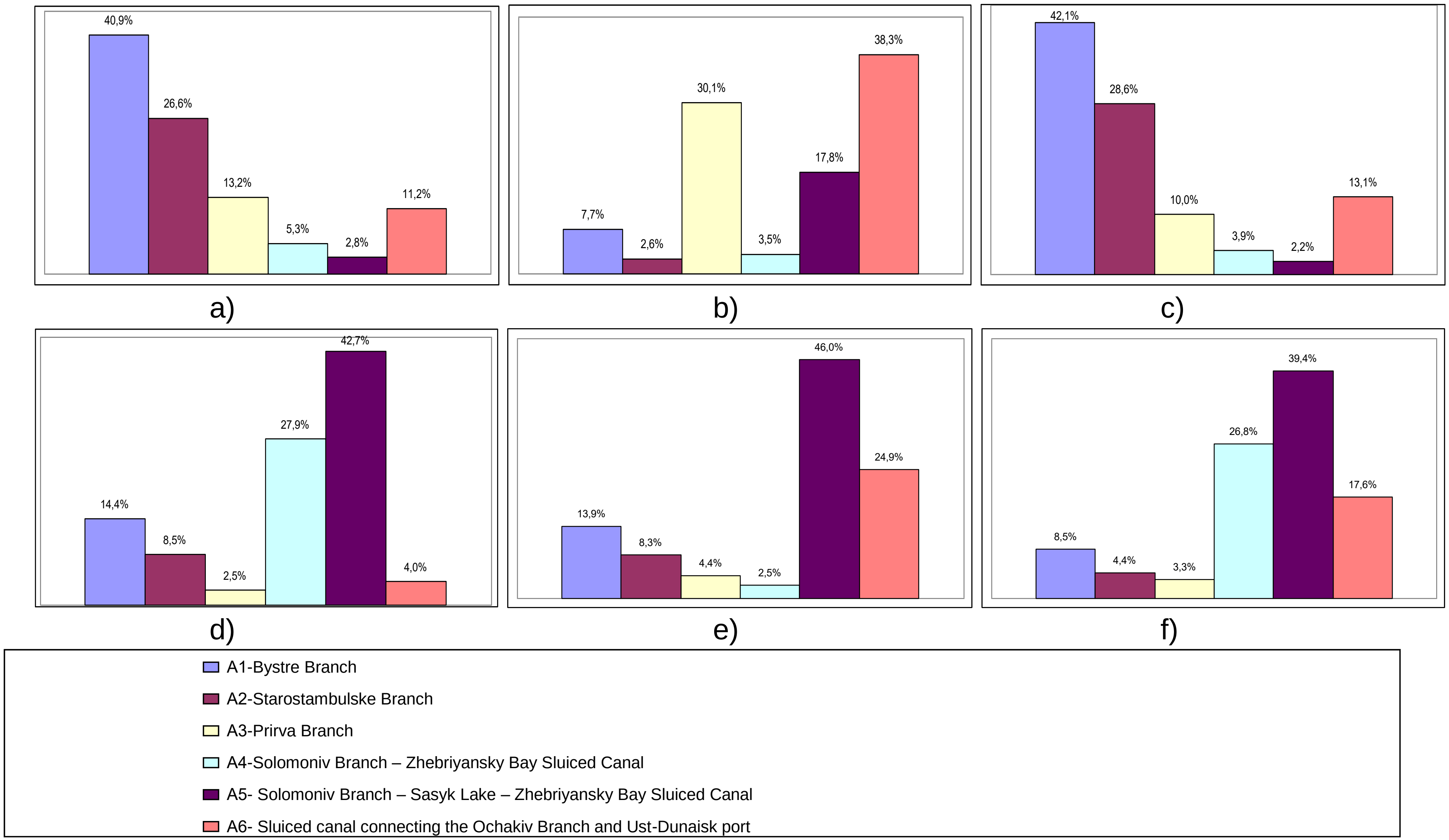

Figure 4.13. Distribution of Priorities among Alternatives A1...A6 in Relation to Specific Impact Factors:
a) land withdrawal (F1); b) route location relative to various zones of the nature reserve (F2); c) construction excavation (dredging) effort (F3); d) maintenance dredging effort (F4); e) impact on hydrological regime of Delta’s islands (F5); f) impact on morphodynamic regime of maritime delta (F6).

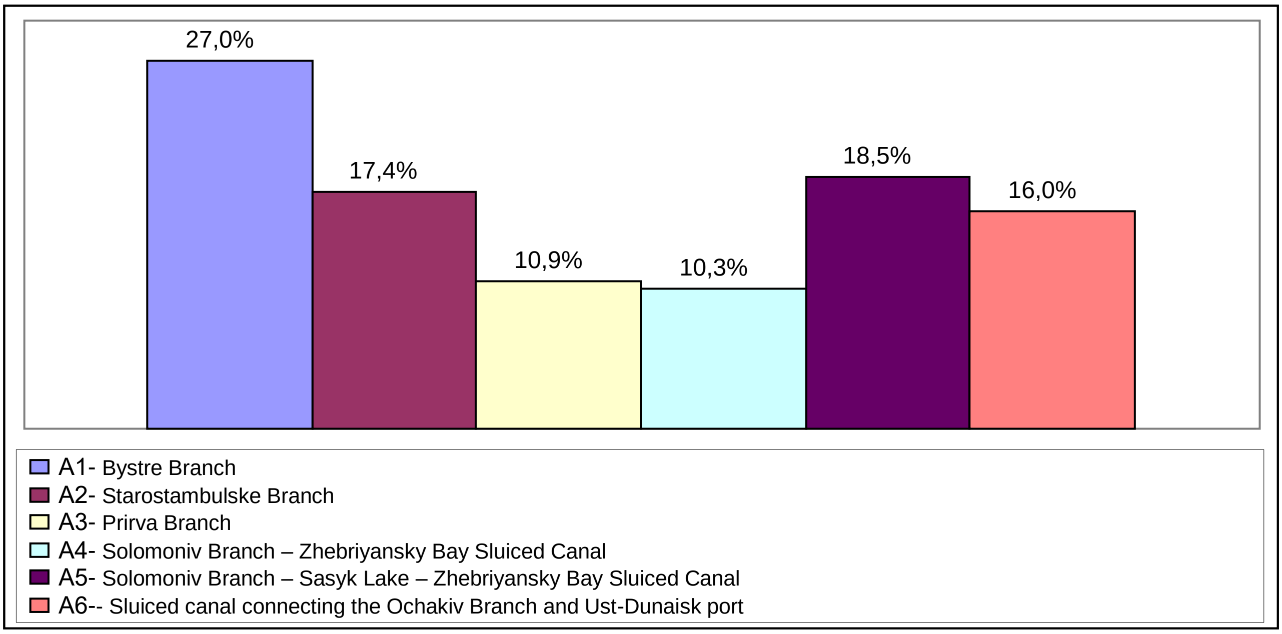

Figure 4.14. Prioritisation of Alternatives A1...A6 Based on the Integral Assessment Results

As can be seen from the diagrams illustrating the distribution of priorities on various levels of the problem hierarchy, the environmental requirements to be met by the Project rank highest among sub-criteria, while transboundary aspects are considered as a relatively low priority (please see Figure 4.9). This can be explained by the fact that the transboundary aspects are closely intertwined with the environmental requirements, and therefore considered to be part of the latter sub-criterion. The picture is somewhat different on the criteria level (C) where the international requirements are considered to represent a high priority, accounting for 48% (please see Figure 4.10). followed by the navigation route depths since this criterion reflects one of the key technical requirements.

On the parameter level (P), where the most important environmental and project parameters are defined (please see Figure 4.11), the highest priority has been assigned to the natural channel depths (because this is a decisive parameter shaping the key impact factors associated with dredging effort involved in the development and maintenance of the navigation route) and presence of protected species habitats along the route (because this environmental parameter is considered to be most susceptible to potential project impacts).

Finally, on the impact factor level (F), the highest priority has been assigned to the required dredging effort during construction and operation (please see Figure 4.8), since this factor is considered to give rise, directly or indirectly, to the majority of potential adverse consequences that may be associated with the proposed activity.

As regards the prioritization of alternative options (A), each specific impact factor yielded a different ranking of options: in terms of land withdrawal (F1) and construction dredging effort (F3), the highest rankings have been assigned to Options A1 and A2; while Options A6 and A3 ranked highest in terms of route location relative to the nature reserve zoning (F2); Options A5 and A4 ranked highest in terms of maintenance dredging effort involved (F4) and impact on morphodynamic regime of maritime delta (F6); and Options A5 and A6 ranked highest in terms of impact on hydrological regime of Delta’s islands (F5) (please see Figure 4.13).

Integral values and global priorities produced through a comprehensive comparative assessment of various alternative options have demonstrated that the Option A1 (Bystre Branch) is significantly more advantageous than other options (please see Figure 4.14)**.**