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DYNAMIC MAPPING OF THE CASPIAN SEA COAST FOR DIFFERENT TIME SCALES

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BACKGROUND AND OBJECTIVES

Sea coasts are complex global ecosystems in the zone of interaction between the lithosphere, the water column, atmosphere, and the artificial anthropogenic environment. A significant part of sea coasts is characterized by instability of the shoreline due to sea level rise, accumulation or destruction of the coast, on the one hand, and increasing anthropogenic press on coastal ecosystems, on the other. This compels to consider the coastal zone (especially the accumulative) as one of the most dynamic and unstable geosystems in the world.

By the nature of the changes there are three main types of coastal geosystem development: super long-term (corresponding to geological stage of development), long-term (secular cycles, multi-year periodicity), short-term (seasonal, episodic, and abrupt). All these changes are accompanied by movements of the coastline and their magnitudes depend on the sea coast type, conditions and factors of coast formation. The highest specificity is low-lying intertidal accumulative coasts with a full set of changes induced by century sea level fluctuations as well as tidal and wind-surge events. Typical for such coasts the small slopes of coastal land and bottom create favorable conditions for moving the shoreline over long distances (from hundreds of meters to tens of kilometers) at various increasing or decreasing the sea level.

The Caspian Sea was chosen as the object of this study. The sea located in the vast continental depression on the border between Europe and Asia is the largest closed lake on the planet. At the same time it has all the features of the sea as in past geological epochs it was due to the ocean.

Level regime of the Caspian Sea is heavily dependent on the inflow of its rivers, precipitation and evaporation, their state and regime are determined by climatic conditions. Changes of sea level has a negative impact on the preservation of natural resources potential primarily on land, fisheries and recreational resources as well as the livelihood of the population and social infrastructure. Understanding the nature of the coast change processes both past and anticipated future is needed to utilize the coastal environment efficiently and to maintain its optimum state.

Below is an overview of noncontemporaneous fluctuations of the Caspian Sea level.

Super long-term changes of the sea level. As follows from paleogeography investigation results the Caspian Sea history consists in transgression and regression alternating each other. The maximum extent of sea level fluctuations during the Pleistocene (that began 1.8 million years ago and ended 10 000 years ago) was 100 m: from - 50 m in the Late Khazarian regression to + 50 m in the period of maximum Early Khvalynian transgression (Leontiev et al., 1977).

Since AD there were observed six major transgressions of the Caspian Sea, each time reduced to flooding coasts for hundreds of kilometers. The Caspian Sea level fluctuations average 14 m (from -34 to -20 m abs) over the last 10 thousand years and 9.7 m (from -34 - -32 to - 25 m abs) over the last 2.5 thousands years (Rychagov, 1997).

Long-term (centuries-old) sea level changes. In the middle of the XVI century the sea level was at elevation -26.6 m, in the following century it rose to the level mark -23.9 m. At the beginning of XVIII century the level dropped to -26.0 m. After this significant reduction the level highstand period began and by the XIX century (1805) his mark reached -22 m. From 1837 (the beginning of instrumental observations) and to the early XX century the level remained near the average position of -25.8 m.

Multiyear (over the last 100 years) sea level changes. From 1900 to 1929 these changes were negligible and occurred near the average mark of -26.2 m. From 1930 to 1941 lowering the level was 1.8 m with average level drop intensity about 16 cm/year and maximum 30-33 cm/year. In subsequent years it was observed some stabilization of the level near the mark of -28.4 m. In the first half of the 70-ies there was sharp level decrease and in 1977 it reached extremely low over the past 150 years mark -29 m. Since 1978 the level of the Caspian Sea began to go up sharply and in 1985 its mark was reached -27.9 m. Ten years later (by the end of 1995) the average mark of the level has risen to -26.6 m. From 1978 to 1995 average speed of raising the level was 13 cm/year reaching 33-35 cm/year in some years. Sea level rise led to continuous flooding the coast at speed of 1-2 km per year. In the early 2000's sea level stabilized near the mark of -27 m.

Sea level fluctuations within the year (seasonal fluctuations). Average long-term value of level changes within the year is low and varies from 25 to 50 cm depending on the dryness of the year.

Short-term occasional sea level fluctuations. The Caspian Sea and especially its shallow northern part takes one of the first places in the world in storm surges and ebbs, and their impact on economic activity and the natural feature formation of the coast. During the period of instrumental observations in the northern part of the sea surges reached the maximum value of 4.5 m (1952) and ebbs culminated 1.7 m (1995), both led to the shoreline displacement by tens of kilometers. Duration of storm winds may range from several hours to 5-6 days. On average 3-4 surges and 2-4 ebbs occurred in the month so the coastline is extremely unstable and constantly migrates According to meteorological observations from 1936 to 2001 on the Russian coast of the Caspian Sea there were observed over 40 dangerous surge flooding that brought huge damage to national economy (Kurbatova & Golubeva, 2005). Thus the Caspian Sea is the largest geosystem virtually with all types of temporary dynamic changes caused by the influence of geological, climatic and meteorological factors.

The high dynamism of level and coastline mobility of the Caspian Sea creates specific conditions for the formation of coastal natural-territorial complexes. Study is highly relevant of these conditions actively influencing the transformation of the Caspian Sea ecosystem and the stability of economic activity. Some priority tasks aimed at showing up zones of affecting level fluctuations taking place at different times are:

- Determination of the coastline location, corresponding to a specific annual or normal annual sea level;
- Estimating the width of the flooding area for different surge magnitude and frequency;
- Studying the influence of the coastline dynamics on the coastal ecosystem formation;
- Assessing stability of the coastal zone as a territory for the construction engineering;
- Assessing safety of the territory under its economic development.

APPROACH AND METHODS

The Caspian Sea is the region representative for the mapping method development of almost all kinds of sea coast zone dynamics in their typical and unique aspects. Developed specialized maps whose content reflects the specific migration of the Caspian Sea shoreline are used for solving several problems associated with its level fluctuations of different periodicity. Traditionally drawn maps of the dynamics are a series of maps with various subjects compiled in a certain sequence and fixing complex or componentwise changes in the natural or socio-economic environment for a specific time interval.

Dynamic mapping in new GIS environment implies continuity of the traditional mapping methods, based on a system approach to the interpretation of geographical, geo-ecological, hydrological and other data. Emerged in the late XX century the term "geovisualization" means the development of electronic mapping applications to visualize the results of researches on various scientific disciplines having a geographical component (MacEachren & Kraak, 2001; Midtbo, 2007). Computer technology of making and demonstrating maps of the natural and anthropogenic process dynamics increase the informative and clear view, provide a high level of the material generality accompanied by quantitative, qualitative and textual features. Animations have not replaced the traditional static mapping. Being developed in computer environment they have expanded the possibilities of mapping supplemented with a new essential dynamic component.

Relations between dynamic phenomena and processes can be analyzed for any time interval. At the same time the researcher is able to manage a dynamic sequence in the interactive mode, stop it, slow down, let in the opposite direction, to change parameters in real or near real-time (Berlyant, 2006). In some cases connection may be established between the map and activated elements of the legend when the legend acts as an interface between the user and interactive map animation. This allows (following Peterson (1999)) using the term "active legend". Similar means was used in present paper (see below).

The most common mode for creating animation is the keyframing method. In its implementation objects are installed manually to the desired position appropriate to time of keyframes and computer animation system builds all the missing frames between bearing ones automatically by portraying objects at intermediate stages of their movement {Lisitsky & Bugakov, 2009). For the most complex configuration the control markers are installed. They calculates current values of animation parameters based on the initial values specified by the user and on the mathematical expressions describing the change in parameters over time.

The paper presents the results of the dynamic mapping the Caspian Sea both in traditional form and on the basis of new computer technologies. These results demonstrate the paleogeographical reconstruction of the Caspian Sea formation stages in the geological epoch and modeling different scale changes in coastal zones over the past century.

RESULTS

In the paper examples has been considered of animated mapping the Caspian Sea in different states using Rich Internet Applications (RIA) technology in the programming environment Adobe Flash CS3 Professional for creating professional animated Flash-files. Three animated subjects have been integrated in the RIA-application:

- paleoreconstruction "Khvalynian and. New Caspian stages of the Caspian Sea history";
- reconstruction "Dynamics of the Northern Caspian coastline in the XX century";
- dynamic cartographical model "Storm surges on the northwest coast of the Caspian Sea".

The main purpose of the study was to develop the RIA-application content and interface. Great attention was paid to design of animated maps. Animated models were based on the content of paleogeographic (Leontiev et al, 1977), hydrological and geo-ecological (Vereshchaka et al, 1999; Kurbatova & Golubeva, 2005) thematic maps resulted from long-term investigations of the Caspian Sea level fluctuations occurring at different time. Careful and thorough preparation of the original mapping data contributed to the reliability, efficiency and detailed visualization of map content.

The starting materials for creating animations were thematic maps developed earlier and thus the animation models became the practical implementation of ready-made maps and integration of theoretical GIS developments.

The main stages of creating named animated maps can be represented as follows:

I. Preparatory stage.

1. The choice of the concept and purpose of multimedia applications.
2. Creating layouts of map composition.
3. The choice of raw materials and bringing them to the optimal projection (individually for each map).
4. Vectorization of original raster materials in Adobe Illustrator CS3 editor.
5. Auxiliary interpolation.

II. Making interactive animated maps.

1. Laying the foundation of application and graphical user interface.
2. Importation of utilized materials into the Adobe Flash application.
3. Creating control cartographic and ancillary image item.

III. Making animations.

1. Creating animation reels (movie clips) for each phase.
2. Combining clips into a single animation.
3. Comparison of animation with timelines and control of animation.

IV. Adjusting the interaction of the map elements and interface elements.

1. Assigning control functions for buttons.
2. Ensuring interactivity.
3. Getting the final version of interactive animated map.

Group of animations in the first plot is intended for imaging configurations of the Caspian Sea reconstructed for the different stages of its geological development (according to Leontiev et al, 1977). Used cartographic material is characterized by small scale (1:10000000) and a large generalization of contours that is due to highly temporal remoteness of events, the complexity and ambiguity of paleogeographic reconstructions. Nevertheless even such generalized version of the developed animation provided a visual presentation on the ancient Caspian Sea shoreline evolution at the time of his various transgressions and estimation of the changes in water area. At the request of the user via the control panel animation can be carried out against both the background of hypsometric maps and modern space image area (Landsat-7), and also change the transparency of the image layer by layer.

Group of animations in the second plot displays long-term sea level fluctuations occurring for the most part as a result of climate changes on the mainland and the sea water balance variations. The Northern Caspian Sea chosen as the object of mapping because of its shallow water is the most indicative to show surface level fluctuations and significant coastline movement. The map of the Northern Caspian Sea coastline dynamics over the past 100 years has been composed in the traditional and digital types (Vereshchaka at al, 1999) as a base map to create animated images. The map of scale 1:1000000 shows the shoreline positions corresponding to a characteristic level for periods of its stability, rise and fall: -26.0 m (the maximum annual average for the century) during 1900 – 1929; -28.0 m (consistently low) during 1942 – 1969; -29.0 m (the minimum for a century) in 1977; -27.8 m (intermediate) during 1985-1987; and modern equal -27.0 m. For mapping data were used of long-term hydro-meteorological observations, topographic maps published in different years and aerospace survey materials. Animated map "Dynamics of the Northern Caspian coastline in the XX Century" was compiled in the same projection as the original map while maintaining degree grid. Processing of source material was to be transferred in vector form because advantage of the Adobe Flash Professional program over bitmap animators is precisely the ability to work with vector information in the Adobe Illustrator CS3 editor. To create a static background with area coast objects (sand, swamps, salt marshes, etc.) there were applied vector editor bitmap effects import of which was possible only for raster images of accessible formats (bmp, jpeg, gif). Certain complexity is making dynamic video images of configuration changes for the numerous Northern Caspian bays and islands when its water level fluctuations occurring. As a result animated map was drawn whose control panel allows:

- to get a clear picture of the coastline recession and progression in chronological order (from 1900 to 2000);
- to obtain layered images of shoreline configuration for its specific dominant positions;
- to assess the area of drainage or flooding in a given time interval, to determine the land retreat and increment (km/year);
- to determine the orientation of geo-ecological changes associated with sea level fluctuations.

The special role of electronic map is the ability to model and substantiate different scenarios of geo-ecological conditions and situation of the North Caspian coast. The possibility of using the database formed in the development of described map to elaborate following thematic maps (with the introduction of new data) is also extremely important.

Geo-ecological interpretation of long-term sea level movements is follows. With sea recession (1930 - 1977) there were occurred shallowing coastal areas of water, increasing salinity of the sea, reducing the area of grazing lands for fish and decreasing numbers of valuable species fish herds, overgrowing vegetation of the Volga shallow offing, change of coastal water-loving vegetation on zonal semi-desert, etc. Upsurge of the sea level (1978-2000) led to the action processes in opposite directions namely flooding and swamping of coastal areas, raising the groundwater level, the restoration of grazing land areas, changing vegetation cover. In the socio-economic sea level rise resulted in flooding human settlements, health centers, industrial facilities, agricultural areas, systems of irrigation, etc. which were built or developed in this area during the sea recession.

Group of animations in the third plot was implemented to determine the boundaries of storm surges on the Russian coast of the North Caspian. Developed conventional version of the map "The Danger of Surge Flooding the North-West Caspian Sea Coast" (Kurbatova & Golubeva, 2005) was used as a base. For mapping the following materials were used: satellite imagery taking place in different time and its landscape indicative interpretation, standard hydro-meteorological observation data, field ground and aerial visual survey results. Verges of flooding coastal areas (zones of flooding) were specified for the storm surges of 1.4, 1.7, 2.1 and 3.0 m height corresponding to the critical, dangerous, particularly dangerous and catastrophic situations (at the sea level of – 28 m). Each zone was described correspondingly as alarming (with flood risk once per 2 years), dangerous (once per 25 years), particularly dangerous (once per 50 years), and extreme (once per 100 years).

The main features of the original map visualization procedures using Flash-application are considered by the example of described storm surge map (Similar operations with minor changes were made when building groups of animations on the remaining two plots). This animation represents the movement of the shoreline and changes of the flood zone width and configuration.

Algorithm of designing Flash-application to create animated map "The Danger of Surge Flooding the North-West Caspian Sea Coast".

1. Creating structure and designing layout of Flash-application.

1.1. Determining the size of the canvas (resolution) - 1200 × 800.

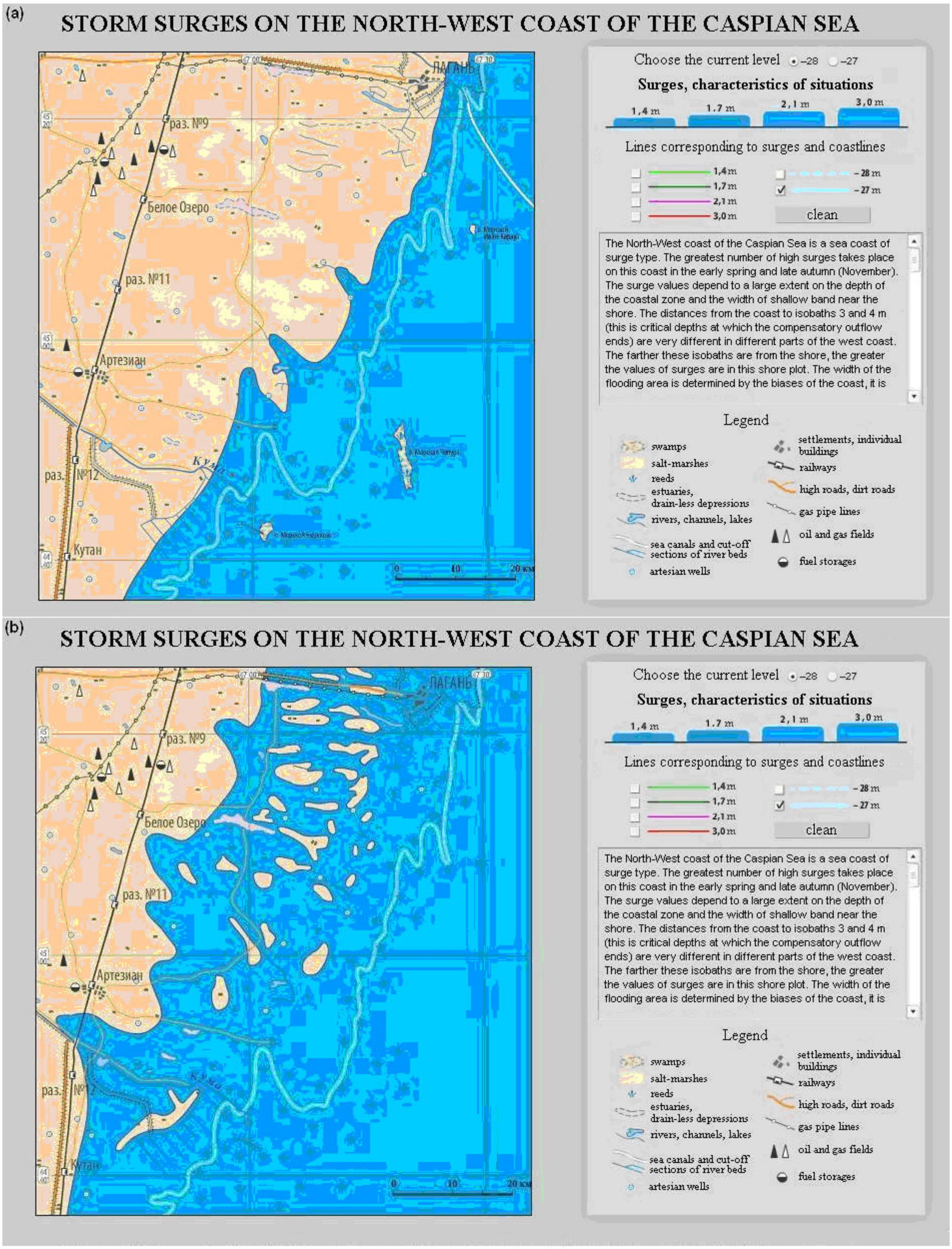
1.2. Choosing interface – Table-menu.

1.3. Creating new document (choosing the version of the programming language - Flash File ActionScript2.0; setting the canvas size - 1200 × 800; specifying frame rate - 20 frames/sec.)

2. Processing of raw material (Map “Danger surges flooding in the north-west coast of the Caspian Sea” scale 1:500 000) and choosing specific area of processing.

2.1. Vectorization of the main elements of content (hydrography, settlements, roads, vegetation and soils, mathematical grid).

2.2. Vectorization of sea levels and surges flooding zones as well as their interpolation (fitting additional lines between available ones).
2.3. Importation into Flash. Choosing vector layers to convert and create animation.
2.4. Procedure “Choosing the current position of the Caspian Sea level depending on conditions and time of using map” (creating movie clip with the two level positions -28 m and -27 m).
2.5. Writing code to manage the situation on the map and in the legend (changing scale, changing labels).
3. Procedure “Magnification of the object (e.g. legend) as appropriate”.
3.1. Creating mask for characters and captions (to make interactivity).
3.2. Making script for scaling up to 130 % when bringing cursor on legend.
3.3. Creating animations of islands, captions and comments.
Example of the original map visualization made using Flash-application is shown in Fig.1.



Fragments of the animation "Storm surges on the North-West coast of the Caspian Sea" at the gauge datum -27 m with inundation surge magnitude 1.4 m (a), 3.0 m (b).

As seen it allows displaying images on the monitor with the following layout: name of the map is located at the top of the screen, window with multilayer animation picture is in the left half of the screen, and control panel, Comments window and Legend are in the right half. The control panel is a group of buttons to combine different sets of layers with the image of the coastline corresponding to the chosen sea level and the selected verges of flooding coastal areas with the surge of set point ("active legend"). For example, choosing one of the baseline marks (- 27 or - 28 m) proposed in the Section Sea Level we obtain an image map of the Northern Caspian Sea coast corresponding to this situation. Then, selecting button of surge magnitude (1.4, 1.7, 2.1 or 3.0 m) in the Section Surges and activating it, we observe the smooth movement of the coastal line deep into the land up to the verge of the flooding with the surge of the set point. The higher the surge and sea level are, the wider the flooded area is. Individual land plots with the relative elevation over the sea level higher than the surge value are marked as “safety islands”. On the coast image one can also mark from 1 to 4 verges of surge-flooded areas without blue pouring in order to observe anthropogenic facilities within the reach of a storm surge. The scale ruler provides additional convenience namely moving it across the image field you can accurately determine the width of the flooding area in a particular location. Thus the researcher has an opportunity to control dynamic sequence interactively, to change numerical values of long- and short-term sea level positions, and to receive animations of forecasted situations.

The Window Comments contains text description of surges as a phenomenon as well as quantitative characteristics of the most catastrophic surges in the North Caspian history.

The Section Legend contains arbitrary signs depicting the main content of the map, including natural (drainage network, sea channels, estuaries, drain-less depressions, bent bogs, marshlands, salt-marshes) and anthropogenic (settlements, traffic net, gas lines, gasoline storages, oil fields) ones.

The map made at a scale of 1:500 000 allowed estimating the dimensions of the flooded areas and areas located in the risk zones of temporary flooding, identifying coastal plots liable to active washing out, assessing the submergence verges for urban territories, industrial district, transport network, and farm lands. Allocation of areas flooded with surges of various values gives an opportunity: firstly, to identify ground-based industrial and agricultural pollution pockets within the surging areas; secondly, to mark the territories prone to the secondary sea water pollution.

CONCLUSION AND FUTURE PLANS

Animated map models of the North Caspian coastline dynamics developed with the help of programming environment Adobe Flash CS3 Professional are easy to use, provide high image fidelity and the binding sites thanks to overlay degree grid, and retain details of the base map content. In addition they provide for measuring work on the screen using a mobile measurement scale corresponding to linear scale. This allows measuring the width of flooding area in a particular location, determining the surface of area flooded by surges of a certain value, as well as assessing “safety islands” sizes.

Designed animated models should be used:

- In scientific and methodological developments aimed at studying the dynamics of the sea level regime and processes inseparably linked with it;
- In the teaching-learning process as an illustration of the new dynamics map generation, in electronic atlases of the scientific reference type and complex mapping encyclopedias;
- To develop operational forecast scenarios of different option combinations for long-term and short-term shoreline movements;
- In GIS developed for the complex assessment of geological and environmental sea conditions;
- For negotiating forward-looking plans of economic territory development and development of measures to reduce property damage from storm flooding.

The future plans include creating animated forecast map of flooding coasts by storm surges of different magnitude and frequency with the possible sea level rise up to gauge datum -26.0 and -25.0 m abs. This allows outlining strategy for economic development of the coastal zone in the precarious Caspian Sea level position.

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