

# Intergovernmental Oceanographic Commission

Workshop Report No. 108 - Supplement



## **UNESCO-IHP-IOC-IAEA Workshop on Sea Level Rise and the Multidisciplinary Studies of Environmental Processes in the Caspian Sea Region**

Paris, France  
9-12 May 1995

**Submitted papers**

**UNESCO**

# IOC Workshop Reports

The Scientific Workshops of the Intergovernmental Oceanographic Commission are sometimes jointly sponsored with other intergovernmental or non-governmental bodies. In most cases, IOC assumes responsibility for printing, and copies may be requested from:

Intergovernmental Oceanographic Commission - UNESCO  
1, rue Miollis, 75732 Paris Cedex 15, France

No.	Title	Languages	No.	Title	Languages	No.	Title	Languages
1	CCOP-IOC, 1974, Metallogenesis, Hydrocarbons and Tectonic Patterns in Eastern Asia (Report of the IOOE Workshop on); Bangkok, Thailand, 24-29 September 1973 UNDP (CCOP), 138 pp.	E (out of stock)	18	IOC/UNESCO Workshop on Syllabus for Training Marine Technicians; Miami, 22-26 May 1978 (UNESCO reports in marine sciences, No. 4 published by the Division of Marine Sciences, UNESCO).	E (out of stock), F, S (out of stock), R	36	IOC/FAO Workshop on the Improved Uses of Research Vessels; Lisbon, 28 May-2 June 1984.	E
2	CICAR Ichthyoplankton Workshop, Mexico City, 16-27 July 1974 (UNESCO Technical Paper in Marine Sciences, No. 20).	E (out of stock) S (out of stock)	19	IOC Workshop on Marine Science Syllabus for Secondary Schools; Llanrwst Major, Wales, U.K., 5-9 June 1978 (UNESCO reports in marine sciences, No. 5, published by the Division of Marine Sciences, UNESCO).	E (out of stock), E, S, R, Ar	36	Papers submitted to the IOC/FAO Workshop on the Improved Uses of Research Vessels; Lisbon, 28 May-2 June 1984.	E Suppl.
3	Report of the IOC/GFCM/ICSEM International Workshop on Marine Pollution in the Mediterranean; Monte Carlo, 9-14 September 1974.	E, F E (out of stock)	20	Second CCOP-IOC Workshop on IOOE Studies of East Asia Tectonics and Resources; Bandung, Indonesia, 17-21 October 1978.	E	37	IOC/UNESCO Workshop on Regional Co-operation in Marine Science in the Central Indian Ocean and Adjacent Seas and Gulfs; Colombo, 8-13 July 1985.	E
4	Report of the Workshop on the Phenomenon known as 'El Niño'; Guayaquil, Ecuador, 4-12 December 1974.	E (out of stock) S (out of stock)	21	Second IOOE Symposium on Turbulence in the Ocean; Liège, Belgium, 7-18 May 1979.	E, F, S, R	38	IOC/ROPME/UNEP Symposium on Fate and Fluxes of Oil Pollutants in the Kuwait Action Plan Region; Basrah, Iraq, 8-12 January 1984.	E
5	IOOE International Workshop on Marine Geology and Geophysics of the Caribbean Region and its Resources; Kingston, Jamaica, 17-22 February 1975.	E (out of stock) S	22	Third IOC/WMO Workshop on Marine Pollution Monitoring; New Delhi, 11-15 February 1980.	E, F, S, R	39	CCOP (SOPAC)-IOC-IFREMER-ORSTOM Workshop on the Uses of Submersibles and Remotely Operated Vehicles in the South Pacific; Suva, Fiji, 24-29 September 1985.	E
6	Report of the CCOP/SOPAC-IOC IOOE International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific; Suva, Fiji, 1-6 September 1975.	E	23	WESTPAC Workshop on the Marine Geology and Geophysics of the North-West Pacific; Tokyo, 27-31 March 1980.	E, R	40	IOC Workshop on the Technical Aspects of Tsunami Analysis, Prediction and Communications; Sidney, B.C., Canada, 29-31 July 1985.	E
7	Report of the Scientific Workshop to Initiate Planning for a Co-operative Investigation in the North and Central Western Indian Ocean, organized within the IOOE under the sponsorship of IOC/FAO (IOFCY/UNESCO/EAC; Nairobi, Kenya, 25 March-2 April 1978.	E, F, S, R	24	WESTPAC Workshop on Coastal Transport of Pollutants; Tokyo, 27-31 March 1980.	E (out of stock)	40	First International Tsunami Workshop on Tsunami Analysis, Prediction and Communications, Submitted Papers; Sidney, B.C., Canada, 29 July - 1 August 1985.	E Suppl.
8	Joint IOC/FAO (IPFC)/UNEP International Workshop on Marine Pollution in East Asian Waters; Penang, 7-13 April 1978.	E (out of stock)	25	Workshop on the Intercalibration of Sampling Procedures of the IOC/WMO UNEP Pilot Project on Monitoring Background Levels of Selected Pollutants in Open-Ocean Waters; Bermuda, 11-26 January 1980.	E (superseded by IOC Technical Series No. 22)	41	First Workshop of Participants in the Joint FAO/IOC/WHO/IAEA/UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region (WACAF/2); Dakar, Senegal, 29 October-1 November 1985.	E
9	IOC/CMG/SCOR Second International Workshop on Marine Geoscience; Mauritius, 9-13 August 1978.	E, F, S, R	26	IOC Workshop on Coastal Area Management in the Caribbean Region; Mexico City, 24 September-5 October 1979.	E, S	43	IOC Workshop on the Results of MEDALPEX and Future Oceanographic Programmes in the Western Mediterranean; Venice, Italy, 23-25 October 1985.	E
10	IOC/WMO Second Workshop on Marine Pollution (Petroleum) Monitoring; Monaco, 14-18 June 1978.	E, F E (out of stock) R	27	CCOP/SOPAC-IOC Second International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific; Nouméa, New Caledonia, 9-15 October 1980.	E	44	IOC-FAO Workshop on Recruitment in Tropical Coastal Demersal Communities; Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986.	E (out of stock) S
11	Report of the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions; Port of Spain, Trinidad, 13-17 December 1978.	E, S (out of stock)	28	FAO/IOC Workshop on the effects of environmental variation on the survival of larval pelagic fishes. Lima, 20 April-5 May 1980.	E	44	IOC-FAO Workshop on Recruitment in Tropical Coastal Demersal Communities, Submitted Papers; Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986.	E Suppl.
11	Collected contributions of invited lecturers and authors to the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions; Port of Spain, Trinidad, 13-17 December 1978.	E (out of stock), S	29	WESTPAC Workshop on Marine Biological Methodology; Tokyo, 9-14 February 1981.	E	45	IOCARIBE Workshop on Physical Oceanography and Climate; Cartagena, Colombia, 19-22 August 1986.	E
12	Report of the IOCARIBE Interdisciplinary Workshop on Scientific Programmes in Support of Fisheries Projects; Fort-de-France, Martinique, 28 November-2 December 1977.	E, F, S	30	International Workshop on Marine Pollution in the South-West Atlantic; Montevideo, 10-14 November 1980.	E (out of stock) S	46	Reunión de Trabajo para Desarrollo del Programa "Ciencia Oceánica en Relación a los Recursos No Vivos en la Región del Atlántico Sud-occidental"; Porto Alegre, Brazil, 7-11 de abril de 1986.	S
13	Report of the IOCARIBE Workshop on Environmental Geology of the Caribbean Coastal Area; Port of Spain, Trinidad, 16-18 January 1978.	E, S	31	Third International Workshop on Marine Geoscience; Heidelberg, 19-24 July 1982.	E, F, S	47	IOC Symposium on Marine Science in the Western Pacific: The Indo-Pacific Convergence; Townsville, 1-6 December 1986.	E
14	IOC/FAO/WHO/UNEP International Workshop on Marine Pollution in the Gulf of Guinea and Adjacent Areas; Abidjan, Côte d'Ivoire, 2-9 May 1978.	E, F	32	UNU/IOC/UNESCO Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the context of the New Ocean Regime; Paris, 27 September-1 October 1982.	E, F, S	48	IOCARIBE Mini-Symposium for the Regional Development of the IOC-UN (OETB) Programme on Ocean Science in Relation to Non-Living Resources (OSNL/R); Havana, Cuba, 4-7 December 1986.	E, S
15	CCPS/FAO/IOC/UNEP International Workshop on Marine Pollution in the South-East Pacific; Santiago de Chile, 6-10 November 1978.	E (out of stock)	32	Papers submitted to the UNU/IOC/UNESCO Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the Context of the New Ocean Regime; Paris, 27 September-1 October 1982.	E	49	AGU-IOC-WMO-CPPS Chapman Conference: An International Symposium on 'El Niño'; Guayaquil, Ecuador, 27-31 October 1986.	E
16	Workshop on the Western Pacific, Tokyo, 19-20 February 1979.	E, F, R	33	Workshop on the IREP Component of the IOC Programme on Ocean Science in Relation to Living Resources (OSL/R); Halifax, 26-30 September 1983.	E	50	CCALR-IOC Scientific Seminar on Antarctic Ocean Variability and its Influence on Marine Living Resources, particularly Krill (organized in collaboration with SCAR and SCOR); Paris, France, 2-6 June 1987.	E
17	Joint IOC/WMO Workshop on Oceanographic Products and the IGOS Data Processing and Services System (IDPSS); Moscow, 9-11 April 1979.	E	34	IOC Workshop on Regional Co-operation in Marine Science in the Central Eastern Atlantic (Western Africa); Tenerife, 12-17 December 1983.	E, F, S	51	CCOP/SOPAC-IOC Workshop on Coastal Processes in the South Pacific Island Nations; Lae, Papua-New Guinea, 1-8 October 1987.	E
17	Papers submitted to the Joint IOC/WMO Seminar on Oceanographic Products and the IGOS Data Processing and Services System; Moscow, 2-6 April 1979.	E	35	CCOP/SOPAC-IOC-UNU Workshop on Basic Geo-scientific Marine Research Required for Assessment of Minerals and Hydrocarbons in the South Pacific; Suva, Fiji, 3-7 October 1983.	E			

CONTINUED ON INSIDE OF BACK COVER

**Intergovernmental Oceanographic Commission**

Workshop Report No. 108 - Supplement

**UNESCO-IHP-IOC-IAEA Workshop  
on Sea Level Rise  
and the Multidisciplinary Studies  
of Environmental Processes  
in the Caspian Sea Region**

Paris, France

9-12 May 1995

**Submitted papers**

# CASPIAN SEA



## LIST OF CONTENTS

	Page
1. Water Balance of the Caspian Sea and Reasons of Water Level Rise in the Caspian Sea (by I. A. Shiklomanov, V. Yu Georgievsky & Z.D. Kopaliani, State Hydrological Institute, Russian Federal Service for Hydrometeorology & Environmental Monitoring)	1
2. Isotope Studies of Caspian Sea Level Rise Implications (by V.I. Ferronsky, V.S. Brezginov, V.V. Romanov, L.S. Vlasova, Water Problems Institute of the Russian Academy of Sciences, and V.A. Polykov, A.F. Bobkov, Research Institute of Hydrogeology and Engineering Geology, Russia)	28
3. Basic approaches to the problems linked to the rise in the level of the Caspian Sea (by K. Salykov, Committee on Water Resources of the Republic of Kazakhstan)	41
4. Determination of Background Value Level of Caspian Sea for Perspective and its Level Rising by Effect of Wind (by A.A. Skakov, V.V. Golubtsov, S.P. Shivareva, Kazakh Scientific Research Hydrometeorological Institute (Kaznigmi) of the Republic of Kazakhstan)	44
5. Long-Standing Fluctuation of the Level and Flooding of the Caspian Sea at the Contemporary Stage (by M. R. Mansimov, State Committee on Hydro-meteorology of the Azerbaijan Republic)	48
6. Caspian Sea Level Rise and associated Ecological and Socio-economic Implications in the Caspian Sea Coastal Area of Turkmenistan (by D.M. Gurbanov, National Co-ordinator on the Caspian Sea Problems of Turkmenistan, Ministry of Nature Exploration and Protection of Turkmenistan)	56

7.	Co-ordination of the tasks ..... 61 to be carried out in Iran in conjunction with the International-Regional Multidisciplinary Studies on the Caspian Sea (by Reza Khazaneh, Atomic Energy Organization of Iran, Republic of Iran)
8.	Realization of the Integrated Programme ..... 67 on Hydrometeorology and Environmental Monitoring in the Caspian Sea Basin - a pre-condition - for the solution of Socio-Economic and Environmental problems in the Region (by A.A. Maximov, Russian Federal Service for Hydro-meteorology and Environmental Monitoring and A.V.Frolov, Hydro-meteorological Center of Russia)
9.	Paleohydrology, paleoclimatology and ..... 79 paleoenvironmental reconstruction of the Caspian Sea during the last tens of thousand years: a clue for understanding causes and mechanisms of its present-day water level fluctuations (by F.Gasse, French Co-ordinator of the programme, contribution of F.Chalié & of French participants: G.Blanc, M.-M.Blanc-Valleron, N.Glauer, A.Desprairies, A.Foucault, P.Gautret-Maire, P.J.Giannesini, E.Gibert, F.Guichard, F.Mélières, F.Orszag, M.Steinberg, N.Tribovillard, D.Badaut-Trauth, P.Tucholka & G.M.Zuppi)
10.	Some tritium and stable ..... 86 isotope measuremental of water samples from the Caspian Sea (by K. Froehlich and K. Rozanski, IAEA)

**WATER BALANCE OF THE CASPIAN SEA  
AND REASONS OF WATER LEVEL RISE IN THE CASPIAN SEA**

I.A.Shiklomanov, V.Yu.Georgievsky & Z.D.Kopaliani  
State Hydrological Institute  
Russian Federal Service for Hydrometeorology & Environmental Monitoring  
Saint Petersburg, Russian

**INTRODUCTION**

**1. General**

The Caspian Sea is the largest endorheic water body; its water area is equal to 376,500 km<sup>2</sup> (without the water area of the Kara-Bogaz-Gol Bay) and the water surface is 28.00 m (BS) below the water surface of the World Ocean; the water volume of the Caspian Sea at the above water level mark is equal to 78,289 km<sup>3</sup>. According to morphometric parameters and hydrological regime, the Caspian Sea is usually separated into three parts, i.e. North Caspian area, Central Caspian area and South Caspian area, which slightly differ in the size but greatly differ in depths and volumes. The South Caspian area is the deepest area (mean depth is 350 m, maximum depth is 1,000 m); two thirds of the whole Sea water volume are concentrated here; the Central Caspian area (mean depth is 190 m) contains about one third of the Sea water volume; the shallow-water North Caspian area with mean depths of 5 or 6 m and maximum depths of 10-25 m contains about 1% of the total water volume of the Caspian Sea. Morphometric parameters of individual parts of the Caspian Sea are given in Table 1. These data demonstrate morphometric peculiarities of the Caspian Sea basin, i.e. sudden changes explained by water areas fluctuations in the North Caspian part, and quite insignificant water areas variations in the Central and South parts. This peculiarity is very important for the Caspian Sea problem.

Table 1 - Morphometric Parameters of the Caspian Sea

Water level, mark (m), (Baltic system-BS)	Water surface area, thou. km <sup>2</sup>				Sea volume, thou. km <sup>2</sup>
	North Caspian part	Central Caspian part	South Caspian part	The whole Caspian Sea (without Kara-Bogaz-Gol Bay)	
-25.97	111.0	138.6	151.4	401.0	79.1
-26.97	104.0	138.2	149.9	392.0	78.7
-28.00	90.3	137.7	148.5	376.5	78.3
-29.00	72.8	137.3	146.9	357.0	77.9
-30.00	62.8	137.0	145.3	345.1	77.6

Mean salinity in the Sea is rather stable and it is about 12.8%, but within the North Caspian part, freshed by the water discharged from the Volga River, the salinity is less (8.5% on average) and it is subject to great time-space variations.

The Caspian Sea is of a great fishery importance; it is one of the most productive large water bodies on the planet. The annual fish catch is equal to 450,000-500,000 tons; moreover, the catch of sturgeons covers 90% of the world catch.

The biological productivity is most impressive in the North Caspian part; during some years the fish catch reaches 40 kg per 1 hectare. Biological processes in the Central Caspian and South Caspian parts are mainly concentrated near the shores in a relatively shallow-water zone up to the depth of 100 m. About 15% of the total biomass of the Caspian Sea are concentrate in the North Caspian part meanwhile the water volume here is less than 1% of the Caspian Sea volume.

The biological productivity of the Caspian Sea mainly depends on the biogenic yield from the Volga River and desalinization of the freshwater shallow North Caspian part by the waters of the Volga and Ural Rivers, providing an effective photosynthesis. Salinity and biogenic saturation of the North Caspian part depend not only on the inflow volume, but on the distribution rate of water over the arms of the Volga and Ural deltas; under natural, undisturbed conditions, this distribution is characterized by much water coming to the west of the North Caspian part and by a limited amount of water discharging to the east of the North Caspian part.

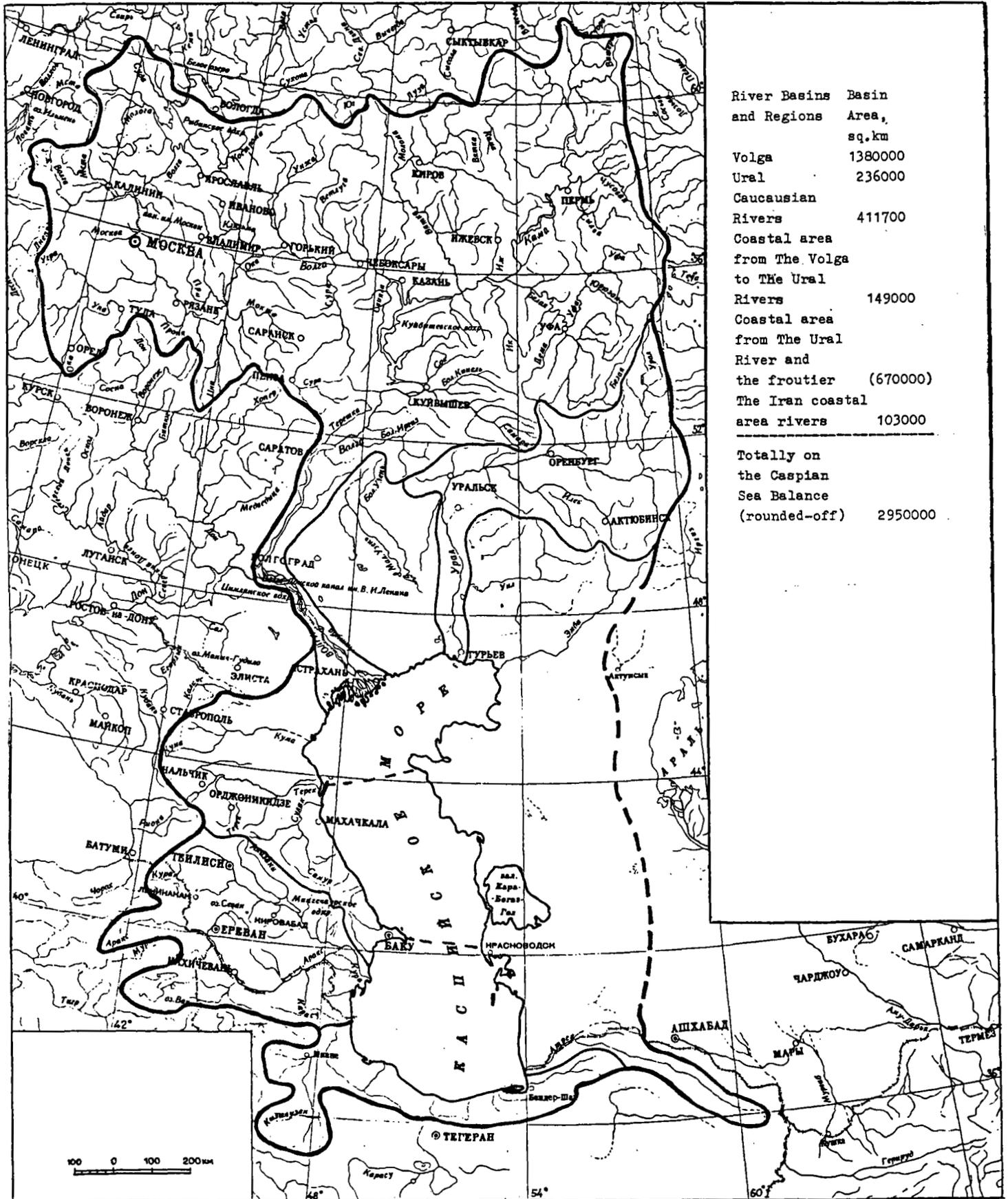
The Caspian Sea receives water flowing from the drainage area of about 3,000,000 km<sup>2</sup> (Fig. 1); 1,616,000 km<sup>2</sup> make the Volga and Ural Rivers basin, 254,000 km<sup>2</sup> are related to the drainage areas of the major Caucasian and Trans-Caucasian rivers (the Kura, Terek, Sulak and Samur Rivers), 103,000 km<sup>2</sup> contribute runoff from the rivers on the Iran coast; small rivers discharging to the Caspian Sea on the western coast from the Volga River up to the Iranian frontier cover the area of 158,000 km<sup>2</sup>, and finally small streams and endorheic areas from the Volga River up to the Ural River and western coast up to the frontier occupy the area of about 819,000 km<sup>2</sup> (Fig. 1). The latter area, though vast by its size, does not provide a permanent outflow to the Sea; thus, the major portion of river runoff to the Caspian Sea is formed within the zone of sufficient and surplus moistening in the forest zone of the European territory of Russia. The Caspian Sea is the largest endorheic water body in the world. Being a unique water body, the Caspian Sea is of a great economic importance for five countries located around the Sea coast (Azerbaijan, Iran, Kazakhstan, Russia and Turkmenistan). Economic efficiency of the Caspian water management, as well as the material well-being of the population of the coastal zone greatly depend on the hydrometeorological regime of the Caspian Sea and on the position of sea water level in particular.

The sea level dynamics, in turn, depends on the nature of variations of hydrometeorological factors, determining the total water availability in the basin, regime of water exchange between sea surface and the atmosphere, and (during recent decades) man's activity mainly connected with the use of water resources. The basic peculiarity of the long-term dynamics of the Caspian Sea level is its sudden water level change for historically short time intervals. Such changes occurred twice during the period of measurements (since 1830). During 1933-1941 the water level fall was 170 cm, during 1978-1994 the sea level rise by 225 cm occurred. These water level fluctuations in the Caspian Sea under the conditions of intensive man's activity cause great damage to economics and ecology of the region, in coastal areas in particular (Fig.2).

After 1978 the water level rise, accompanied by flooding of vast areas and by producing shallow water table around the flooded areas, resulted in an extreme situation in the Caspian Sea region under the conditions of intensive man's impact and ever-growing contamination of the natural waters. Buildings and different structures are ruined in the coastal zone, the roads are flooded, beaches and agricultural lands are flooded too. A negative effect of wind setups, storm waves and other natural disasters is intensified. The sea level rise introduces fundamental change into hydrometeorological and ecological processes in the coastal zone and delta areas in particular.

All these events require urgent measures to protect the coastal areas, to improve the ecology in the region, to organize an effective monitoring system of the major components of the environment. For future projects, for a development of the general strategy and multipurpose measures on the reliable operation of the Caspian water management complex under the conditions of great water level fluctuations in the Caspian Sea it is necessary to make scientifically validated forecasts (computations) of possible sea water level for the nearest and remote future. These forecasts and computations should be based on the detailed water balance of the Caspian Sea.

Fig. 1. The Caspian Sea Basin



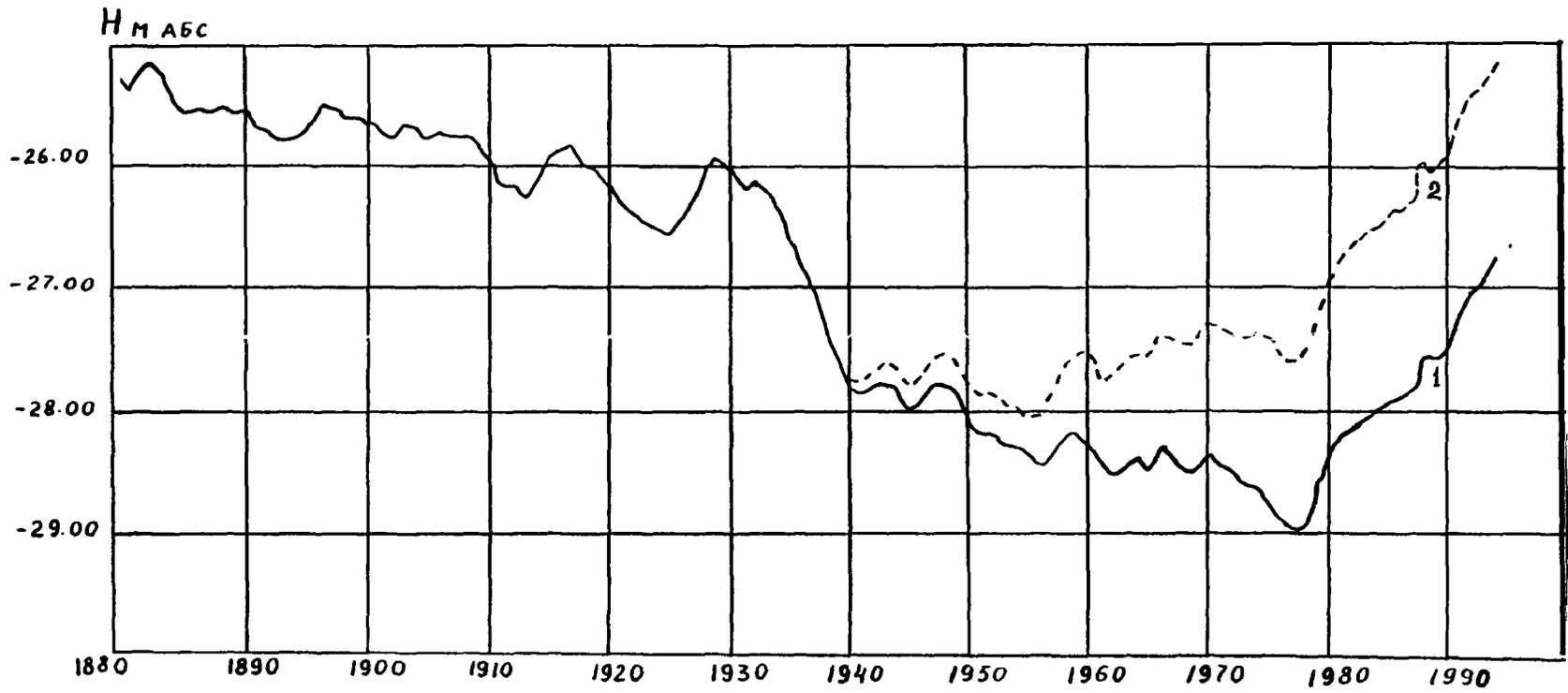


Fig. 2. Observed (1) and recovered (2) Caspian Sea levels

## 2. Determination of Water Balance Components of the Caspian Sea from Observation Data

Investigations of the Caspian Sea water balance are made for more than 100 years. The Caspian Sea water balance was first made by A.I. Voejkov in 1884. Most detailed investigations were made by B.D. Zaikov at the State Hydrological Institute (I5) because of a critical fall of the Sea water level during 1930s'; he used all the available information and prepared a detailed water balance of the Caspian Sea by years from 1878 to 1945 and proved quite evidently that water levels fluctuations depended on the natural cyclic variations of the climate factors.

During 1950s-1970s the water balance of the Caspian Sea was of a great interest due to a construction of a system of reservoirs in the Volga River and an intensive development of water-consuming industries and irrigation development in the basins of rivers discharging to the Caspian Sea, which should result in less water inflow to the sea and further fall of its water level. During those years the water balance of the Caspian Sea was estimated by many scientists. The data on the Caspian Sea water balance obtained at the State Hydrological Institute (SHI) and at the State Oceanography Institute (SOI) (3) are used in the present paper.

**Sea water level.** Instrumental measurements of Sea water level were initiated in 1930 at Baku; since 1837 systematic measurements are made at this site. At the end of the XIXth century and early in the XXth century stations for water level measurements were organized at many sites along the coast (Fig.2) The number of water-level stations at the Caspian Sea differed depending on the position of the sea level. E.g., when a sudden water level fall occurred during 1930s, some of these stations appeared to be far from the coast. On the contrary, the present water level rise in the Caspian Sea caused the overflow of some stations and they do not operate any longer.

Since January, 1961 sea level characteristics are given relative to the exceedence above the single gauge datum, which was accepted to be equal to 28.0 m for the Caspian Sea relative to the zero gauge datum at Kronshtadt ("Baltic System of Elevations").

During computations of annual increments of water levels and of mean annual values the observation data from the stations at Baku, Makhachkala, port Shevchenko and Krasnovodsk were used. Comparison of the results of water level computations for the four stations with the results obtained for 22-26 stations proves that the data are representative. The accuracy of computing annual water level increments is within  $\pm 2-3$  cm.

**River water inflow to the Caspian Sea.** The Volga River is the main watercourse which carries its water to the Caspian Sea. As regular observations of river runoff are made at Volgograd since 1878, it prevents from rough errors during total water inflow during particular years, because the Volga River gives more than 80% of the total water inflow to the Sea. Runoff, computed at Volgograd, however, cannot be directly used as the Volga inflow to the Sea because much water is lost for evaporation from the Volga-Akhtuba floodplain and from the delta overflown during spring snowmelt floods.

More accurate computation of runoff losses from the Volga downstream Volgograd would make the computation error less significant; therefore detailed investigations were made at the SHI on the computation of water inflow to the Sea; those investigations were based on the use of network hydrological data, on special experimental studies and on detailed information on the types of lands in the floodplain and in the delta, as well as on the information on the rate of flooding. I.A. Shiklomanov and V.P. Kozhevnikov (29) computed water losses from different reaches of the floodplain and from the delta year by year for the period of 1936-1970; and they discovered the laws of water losses variations depending on meteorological factors, depth and duration of the spring snowmelt flood and on the rate of man's activity in the river basin. The discovered laws made it possible to compute water losses during the years for which water balance of the Caspian Sea was computed (1880-1990). Mean runoff losses from the Volga River downstream Volgograd appeared to be equal to about  $14 \text{ km}^3/\text{year}$  with variations from  $9-10 \text{ km}^3/\text{year}$  up to  $18-20 \text{ km}^3/\text{year}$ . When water inflow to the Sea from the Volga River was computed during the last decade, data on river runoff at Verkhnee Lebiazhie were used with the account of runoff losses in the delta.

Mean annual runoff in the Volga River at Volgograd during 1880-1993 was equal to 252 km<sup>3</sup>/year, and discharge at the mouth was equal to 238 km<sup>3</sup>/year.

Discharge of the **Ural River** was computed from the data at Topoli and Guriev stations for the periods of 1936-1941 and 1943-1993. Water discharges from 1881 to 1935 and for 1942 were recovered from the runoff relations in the Sakmara River at Sakmara. Runoff for 1880 was accepted to be equal to mean annual runoff for the whole observation period (8.4 km<sup>3</sup>/year). Assessment of runoff change in the Ural River downstream Topoli was made on the basis of studies of the KAZNIIGMI. Mean runoff losses were equal to 0.7 km<sup>3</sup>/year. Moreover, runoff losses may be higher up to 1.5-2.0 km<sup>3</sup>/year during wet years and they may be lower up to 0.2-0.3 km<sup>3</sup>/year during dry years.

The **Kura River** runoff follows next by its amount discharged to the Caspian Sea; discharge measurements at Salyany characterize the amount of water flowing to the Caspian Sea. Observations at Salyany are made since 1930. Discharge at Salyany for the period of 1904-1929 was recovered from the Kura River relations at Mingechaur. When the Kura River discharge to the Caspian Sea during the last decades was computed, data were used on water inflow to the Sea from the collectors and on runoff losses downstream Salyany under the effect of man's activity. Mean Kura River runoff for the period of 1904-1993 to the Caspian Sea was equal to 16.8 km<sup>3</sup>/year.

The **Terek River** discharge is usually computed from the observation data at Kargalinskaya located at the delta head. Downstream Kargalinskaya runoff losses from the Terek River delta occur due to evaporation and water diversions for different economic needs. The amount of runoff losses was received from special field hydrometric measurements in all delta watercourses discharging to the Sea, as well as in small rivers and in the collectors on the reach from the Kuma river up to the Samur river; these measurements were made by the SHI during 1970s (30). Runoff losses for 1904-1945 and for 1978-1993 were determined on the basis of water inflow to the delta head. Mean water discharge for the period of 1904-1993 in the Terek River at Kargalinskaya was equal to 8.9 km<sup>3</sup>/year and at the mouth - 7.4 km<sup>3</sup>/year.

Discharge of the **Sulak River** was determined from observation data at Miatly; during 1969-1993 it was computed on the basis of measurements at Glavny Sulak located 8 km far from the mouth. Runoff losses downstream Miatly were determined from experimental data obtained by the field team of the SHI, analysis of network data and information on water diversions and on irrigated areas (30). Mean runoff losses for 1904-1993 downstream Miatly were equal to 1.0 km<sup>3</sup>/year. Water inflow to the Sea from the Sulak River for that period was equal to 4.5 km<sup>3</sup>/year.

The same approach was applied to compute water inflow to the Sea from the Samur river. During 1930-1957 runoff losses in the downstream Samur reaches were equal to 0.3 km<sup>3</sup>/year on average; during 1958-1977 those losses were equal to 0.9 km<sup>3</sup>/year. Mean annual discharge of the Samur river to the Caspian Sea during 1904-1993 was equal to 2.7 km<sup>3</sup>/year.

When water inflow to the Sea from **small rivers** of the western coast of the Caspian Sea was computed, it was estimated quite approximately because of inadequate information and it was not differentiated by years. Field investigations made by the SHI teams to study water inflow to the Sea from small rivers and collectors of Dagestan, as well as the use of the hydrometric data available up to 1990 (inclusive) made it possible to correct the discharge of small Caucasian rivers to the Sea. Data on 34 rivers were used to determine water inflow to the Sea. The inflow for each year during the period from 1930 to 1990 was computed. Mean water inflow to the Sea was equal to 2.1 km<sup>3</sup>/year during that period. Water discharge to the Caspian Sea during 1904-1929 was accepted to be equal to mean discharge for all those years.

To estimate water discharge to the Caspian Sea from the **rivers of the Iranian coast** the observed runoff data for 1951-1972 were used. Mean discharge for that period was equal to 10 km<sup>3</sup>/year. Inflow to the Sea for 1904-1950 and 1973-1977 was recovered from the relations on the Kura River runoff at Sabirabad, Mean value of water inflow from the rivers of the Iranian coast for 74 years was equal to 10.1 km<sup>3</sup>/year, i.e., it was coincident to the value determined from hydrometric data. It should be noted that the amount of water inflow to the Sea from the rivers of Iran should be calculated

more accurately with the account of hydrological observation data for the recent years and with the account of runoff variations on the reaches from outlets to the mouths.

Data on river runoff to the Caspian Sea were used to compute the total surface inflow to the Sea for 1904-1993. When water inflow was calculated for 1880-1903, the water discharges for all rivers, except the Volga and Ural Rivers, were accepted to be equal to the norm. Water inflow to the Sea mean for the study period was equal to 288 km<sup>3</sup>/year.

The income part of the water balance contains surface inflow which equals 74-85% on average, out of which the share of 85% is contributed by the Volga River, therefore water level fluctuations in the Sea greatly depend on the Volga discharge variations. Coefficient of runoff variations for the Volga River is equal to 0.19.

Runoff from the Ural River is most variable from year to year ( $C_v = 0.59$ ); river runoff from the Iranian coast is variable too ( $C_v = 0.28$ ). Runoff variations for the Kura and Terek Rivers are less significant and are equal to 0.18 and 0.14, respectively.

**Underground water inflow.** Underground water inflow to the Caspian Sea is most difficult to computations, therefore, it is not sufficiently studied as water balance component. Most detailed survey of studies on this problem is given in (16). B.D. Zaikov (15) determined the underground water inflow to the Caspian Sea from direct geohydrological investigations, though quite limited, but the approximate estimate was equal to 5.5 km<sup>3</sup>/year.

The collection and storage of geohydrological data on the conditions of the Caspian Sea coast made it possible to estimate the underground water inflow to the Sea more accurately. At present most of the scientists assume that on average about 3-5 km<sup>3</sup>/year of underground water outflow to the Caspian Sea.

During water balance computations the value of the underground water inflow to the Caspian Sea was taken as constant and equal to 5 km<sup>3</sup>/year; therefore, its share in the water balance, if compared with the shares of other water balance components, is quite small and cannot affect water level fluctuations in the Caspian Sea.

**Precipitation.** Precipitation onto the surface of the Caspian sea are determined from the observation data at meteorological stations installed along the coast and on islands. Arbitrary selection of sites for these stations, different approaches to space interpolation of the measured precipitation cause a great discrepancy in long-term mean precipitation obtained by different scientists (from 170 mm/year up to 250 mm/year) (13).

Discrepancies in the depth of precipitation for particular years are even more significant which shows great errors in precipitation measurements.

The methodology of the SOI (which is most reasonable, in our opinion) for the computation of evaporation from the sea surface has been applied in the present paper (13). This methodology takes into account precipitation distribution data not only over coastal and island stations but stations on boats and ships. Appropriate corrections have been introduced to the precipitation data; these corrections take into account underestimation of precipitation for the wetting of the walls of the receiving vessels, evaporation from the vessel for the periods between rainfalls and between the measurements resulted from wind effect.

Twelve basic stations were used for the computation of annual precipitation onto the surface of the Caspian Sea. Precipitation for the whole Caspian Sea was measured for three sectors of the Sea; the areas of these sectors were determined depending on the mean water level during a particular year. Precipitation norm onto the Sea surface was equal to 240 mm, variation coefficient  $C_v = 0.165$ .

**Evaporation.** Evaporation from water surface is very difficult for determination (which is the main outcome water balance component). Therefore, evaporation is often computed as a residual term

of the water balance equation. This approach is quite reasonable in case of a reliable, independent determination of all main water balance components, surface inflow and level increment in particular. Mean depth of evaporation for the period from 1880 to 1993 equals 975 mm; variability of annual evaporation values is insignificant and equals 0.07; distribution of evaporation is close to normal.

To control evaporation from Sea surface, obtained as a residual term of the water balance and which includes the errors of all other balance terms determination, to analyse dependence of evaporation upon natural hydrometeorological factors, to analyse discrepancies on the Caspian water balance when its components are determined independently, evaporation is computed by the formulas which take into account the physical features of the process. The formulas of Bigelow, Meir, Sverdrup and Samoilenko. These formulas represent different versions of the diffusion method for evaporation determination. The latest investigations of the assessment of evaporation by an independent way were made at SOI and at IWP (Institute of Water Problems). According to (3) the depth of evaporation for 1900-1990 is equal to 973 mm/year; G.N. Panin estimated mean long-term evaporation to be equal to 963 mm/year (18).

It is evident, that evaporation norms obtained as the residual term by the water balance method and independently by diffusion formulas, provide almost similar results.

**Discharge to the Kara-Bogaz-Gol Bay.** Discharge to the Kara-Bogaz-Gol Bay is an outcome term of the Caspian water balance. The Bay is connected with the Caspian Sea by a shallow strait of the same name. Discharge of sea water to the Bay depends on the water-level difference in the Sea and in the Bay.

Systematic observations of water outflow from the Caspian Sea to the Kara-Bogaz-Gol Bay are made since 1928. Observation data for 1921-1927 are quite approximate because of inadequate discharge measurements and insufficient accuracy of these measurements. Therefore, we have to apply indirect methods to determine water outflow to the Bay for the period before 1928. Detailed investigations on water outflow to the Bay during those years were made by B.D. Zaikov (15). B.D. Zaikov plotted a dependence between annual discharge to the Bay, mean annual water level of the Caspian Sea and total surface water inflow to the Sea. Annual discharge values determined by B.D. Zaikov for the period of 1880-1927 were used at the compilation of the Caspian water balance. During that period the annual water outflow from the Caspian Sea to the Bay was equal to 20-25 km<sup>3</sup>. After 1928 the water outflow to the Bay was determined by direct water discharge measurements. Due to a sudden water level fall during 1930s and later up to 1977 in the Caspian Sea, water inflow to the Bay was reduced. By the middle of 1960s the amount of water inflow to the Kara-Bogaz-Gol Bay was equal to 8-10 km<sup>3</sup>/year, by the middle of 1970s the water inflow to the Bay was reduced up to 4-6 km<sup>3</sup>/year.

In March 1980 the Kara-Bogaz-Gol strait was blocked by a dam and sea water could not penetrate into the Bay. In September, 1984, a temporary opening was made in the dam to provide water inflow to the Kara-Bogaz-Gol Bay; since that time up to early 1990s about 1.6 km<sup>3</sup>/year of sea water penetrated into the Bay. During recent years the dam was dismantled; at present water inflow to the Bay depends on the position of the water level in the Caspian Sea. In 1992 the approximate outflow of water from the Sea to the Bay was equal to 13 km<sup>3</sup>/year, in 1993 it was 31.6 km<sup>3</sup>/year. Assessment of water volume from the Caspian Sea to the Kara-Bogaz-Gol Bay during the last years and its dependence on the water level in the Sea should be made more precised.

### **3. Water Balance of the Caspian Sea for Individual Long-Term Periods and Reasons for Sea Level Rise during the last years**

Table 2 gives data on the water balance of the Caspian Sea for different time intervals. Analysis of data from Table 2 makes it possible to explain fluctuations of the Sea water levels for individual long-term periods, including intensive water level rise observed during the recent years.

During 1880-1913 the water level in the Caspian Sea became 92 cm lower though the total water inflow to the Sea was above the norm (301.3 km<sup>3</sup>/year), and mean value of the conventional evaporation\* was below the norm (71.5 cm/year). This is explained by the fact the total water inflow to the Sea should be at least 312 km<sup>3</sup>/year to maintain the water level at the level mark of 25.5 m (BS) about which it was during 1880s, even in case of conventional evaporation to be below the norm.

\* Conventional evaporation = evaporation from the Sea surface minus precipitation onto the Sea surface.

Table 2 - Water Balance Components of the Caspian Sea for Different Time Periods

Periods	Sea level increment	Inflow to the Caspian Sea*		Outflow to Kara-Bogaz-Gol		.. Conventional evaporation
	cm	km <sup>3</sup>	cm	km <sup>3</sup>	cm	cm
1880-1913	-92	306	75.5	27.4	0.7	71.5
1914-1932	16	321	80.4	19.7	4.9	74.7
1933-1940	-172	229	58.5	10.5	2.7	77.3
1941-1956	-61	292	77.5	11.6	3.1	78.2
1957-1970	-4	281	75.5	9.5	2.6	73.2
1971-1977	-61	236	65.2	6.9	1.9	72.0
1978-1993	229	312	82.8	4.4	1.1	67.0
1880-1993	-145	294	75.3	16.6	4.2	73.5

\* Including underground water inflow which is equal to 5 km<sup>3</sup>/year

The period of 1914-1932 was characterised by income part of the water balance above the outcome part. This was explained by the exceeded total water inflow the mean value of which was equal to 316,1 km<sup>3</sup>/year for 19 years at the evaporation depth of the normal value. Values given in Table 2 for the water balance components of the Caspian Sea for these years should be considered as one of the variants of their ratio required to maintain the water level at the level mark of 26.00 mm (BS).

During 1933-1940 the water level in the Caspian Sea fell by 172 cm. This occurred due a critical reduction of income components of the water balance, inflow in particular, the mean value of which was equal to 223.7 km<sup>3</sup>/year or by 72.3 km<sup>3</sup>/year below the norm. The increased evaporation also contributed to water level fall. During subsequent 16 years (1941-1956) the water level fell by 61 cm. During that period mean value of the conventional evaporation was equal to 78.2 cm/year which led to greater water losses at the specified water area of the Sea. Mean water inflow to the Sea during that period was less than a norm by 8.8 km<sup>3</sup>/year. km<sup>3</sup>/year.

During the period of 1957-1970 the water level was stable, at the water level mark of 28.5 m (BS). The difference between water level marks at the beginning and at the end of that period was equal to 4 cm. Mean values of water inflow and of conventional evaporation were equal to 276.3 km<sup>3</sup>/year and 73.2 cm/year, respectively. A comparison of water balance components of the Caspian Sea during 1914-1932 and during 1957-1970 (when water level varied at the water level marks of -26.0 m and -28.5 m, respectively) demonstrates a mechanism of the reactive factor effect, i.e., dependence between the sea filling and the amount of water losses out of the sea. During the first period the higher water level and, consequently, a greater evaporating surface resulted in much more water losses even at the conventional evaporation close to the norm which compensated the increase of the total inflow which appeared to be by 20 km<sup>3</sup>/year higher than the norm. On the contrary, during the second period (1957-1970), at the reduced evaporating surface and at the conventional evaporation below the norm, the water inflow to 276.3 km<sup>3</sup>/year was quite sufficient to maintain the water level at

the water level mark of -28.5 m. It should be noted, that if mean inflow for that period were the same as during 1904-1933, the water level rise would be equal to 146 cm. Thus, it demonstrates one of the factors of water level fluctuations in closed water bodies. i.e., high water levels tend to fall and low water levels tend to rise.

A considerable decrease of the total water inflow to the Caspian Sea during 1971-1977, which was equal to 251 km<sup>3</sup>/year on average, resulted in a further water level fall by 61 cm. The depth of the conventional evaporation for that period was below the norm (72.0 cm/year).

Let us describe the water balance components for 1978-1993, when a high water level rise by 2.29 m occurred which caused the flooding of the coast and rise of the water table around the flooded terrain and produced significant economic and ecological damage. It should be noted that there is no unanimous opinion among the scientists on the reasons of this water level rise. Most of the specialists, however, engaged in the Caspian Sea problem assume that the climate factors determine the long-term fluctuations of the water levels in the Sea; other hypotheses are made too.

Tectonic processes are sometimes considered as the reason of water level change in the Caspian Sea. Tectonic processes do occur on the Caspian Sea coast, nevertheless, it should be emphasized, as some scientists assume (6), that tectonic shifts do not exceed several millimetres per year, therefore, they cannot produce significant water level fluctuations.

According to one more hypothesis, made by N.A. Shilo and M.I. Krivoshei (25), compressing tensions in some rocks and in folded structures produce inter-capillary water yield to the sea, in case of expanding tensions water from the sea is absorbed by these rocks. Water level rise occurs during the compressing phase, the water level fall is observed during the expanding phase.

This problem was specially studied by N.V. Koronovsky and N.A. Goncharov. According to their opinion this hypothesis is not convincing and it is hardly probable.

All these viewpoints cause a necessity of a detailed analysis of hydrometeorological conditions for the periods during which sudden changes in the sea water levels were observed.

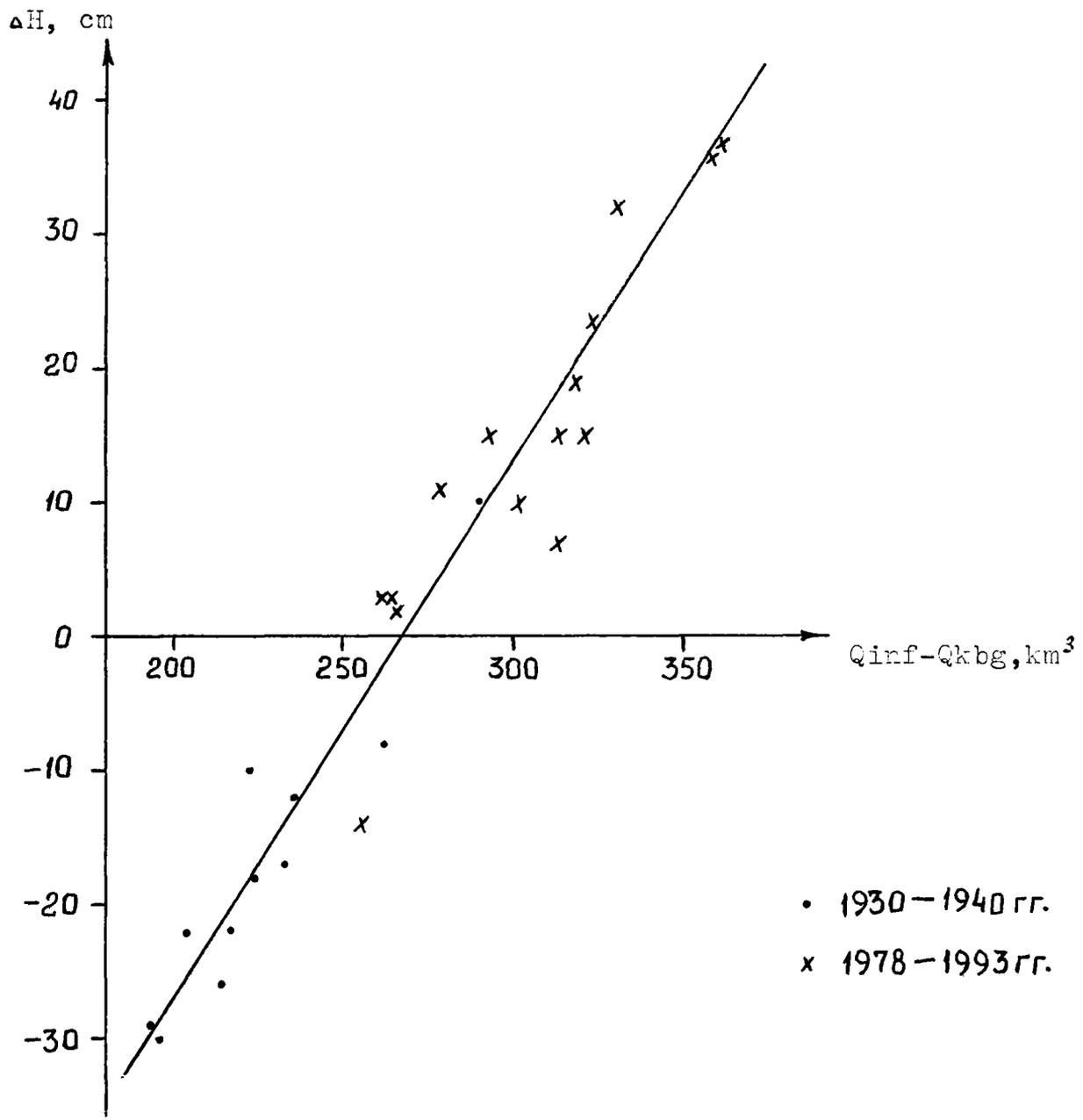
Data on river water inflow to the Sea for 1978-1993 are given in Table 3.

The total river water inflow for these years was equal to 307 km<sup>3</sup>/year, which was by 18 km<sup>3</sup>/year greater than mean long-term water inflow. The Volga River contributed 84% of the total water inflow to the Sea. The water inflow from the Volga River for 1978-1993 exceeded the mean long-term value by 21 km<sup>3</sup>/year; it was by 45 km<sup>3</sup>/year greater than the water inflow during the period of water level fall in the Caspian Sea in 1933-1977. The Volga River discharge to the Caspian Sea was particularly great in 1990 (310 km<sup>3</sup>/year) and in 1991 (307 km<sup>3</sup>/year). During those two years only the water level rise was equal to 73 cm.

Fig. 3 is a graph of dependence of annual sea level increments upon total water inflow from the rivers (minus outflow to the Kara-Bogaz-Gol Bay) for 1978-1993. Data are also given in Fig. 3 which characterize this dependence for the period of 1930-1940 when water level fall was not great.

The analysis of this dependence makes it possible to conclude that the reason of great variations in the Caspian Sea water levels is in variable water inflow from the discharging rivers. As it follows from Fig. 3, when the total water inflow to the Sea equals 340-365 km<sup>3</sup>/year, the water level rise exceeds 30 cm; if the water inflow to the Sea equals about 200-220 km<sup>3</sup>/year, the water level falls by 20-30 cm. A succession of wet or dry years causes extreme increments to the water level.

Fig. 3. Relation between the Caspian Sea level changes ( $\Delta H$ ) and difference of the inflow into the Caspian Sea ( $Q_{inf}$ ) and inflow from the Sea into the Kara-Bugaz-Gol Bay ( $Q_{kbg}$ )



$$H=f(Q_{inf}-Q_{kbg})$$

Table 3 - River Water Inflow to the Caspian Sea during 1978-1993 (km<sup>3</sup>/year)

Years	Volga River	Ural river	Rivers discharging from Caucasian and Iranian coasts	Total water inflow to the Caspian Sea
1978	269	5.29	50.5	325
1979	297	6.24	34.8	338
1980	237	6.01	34.9	278
1981	280	9.24	35.1	324
1982	212	6.31	45.4	264
1983	220	9.46	35.2	265
1984	216	4.24	43.0	263
1985	285	9.08	28.6	323
1986	282	8.93	23.6	315
1987	263	11.20	40.5	315
1988	216	9.10	49.9	275
1989	214	6.84	35.9	257
1990	310	13.20	40.3	363
1991	307	13.20	41.0	361
1992	257	6.10	44.3	307
1993	270	17.00	46.8	334
1978-1993	259	8.80	39.4	307
Mean long-term value	238	7.70	42.8	289

A scattering of points in Fig. 3 is explained by the fact that the water level increment depends not only on the amount of water inflow to the Sea but on the area of the Sea surface, on evaporation from the surface of the Sea and on precipitation.

The Sea surface effect is displayed in the fact that at a high water level the probability of its positive increments is less than at the negative increments; at low water levels the situation is opposite. For example, a long-term water level fall (since the end of the last century up to 1977) resulted in a decrease of the sea water surface. At greater sea surface e.g., the water area of the early 1900s, the present water level rise would be twice slower.

Water level fluctuations in the Caspian Sea also depend on the ratio between precipitation and evaporation. As it follows from the data given in Table 4, the depth of the conventional evaporation during 1978-1993 was approximately by 6.0 cm/year below the norm. Moreover, the depth of evaporation from water surface was less than mean long-term value by about 4.0 cm/year and the total annual precipitation onto the Sea surface was higher by 2.0 cm/year. It should be noted here, that the assessment of the conventional evaporation during 1978-1993, obtained as a residual term of the water balance is in the agreement with the value computed at the SOI depending on the main characteristics determined from the observation data of coastal and island stations. This evident decrease of the conventional evaporation was explained by lower evaporation from the Sea surface and by higher precipitation. A negative trend in evaporation from the Sea surface during the recent decades is proved by the data shown in Fig. 4. There are some grounds to say about this trend not only relative to the Sea surface but to larger regions. The analysis of long-term data on evaporation from water surface made during the last years at the specialized water-evaporation network makes it possible to conclude that an evident systematic decrease of evaporation is observed on the European territory of the FSU.

Table 4 - Water Balance of the Caspian Sea for 1978-1993

Years	Sea level Water inflow increment to the Sea			Outflow to Kara-Bogaz Gol Bay		Conventional evaporation
	cm	km <sup>3</sup> *	cm	km <sup>3</sup> *	cm	cm
1978	19	330	92.4	5.7	1.6	71.8
1979	32	343	94.9	7.1	2.0	60.9
1980	11	283	77.9	0.0	0.0	66.9
1981	23	329	88.9	0.0	0.0	64.9
1982	3	269	72.3	0.0	0.0	69.3
1983	2	270	72.3	0.0	0.0	70.3
1984	-3	268	71.4	1.0	0.3	68.1
1985	15	328	87.0	1.8	0.5	71.5
1986	7	320	84.8	2.0	0.5	77.3
1987	15	320	84.3	1.6	0.4	68.9
1988	15	280	73.3	1.6	0.4	57.9
1989	-14	262	68.5	1.6	0.4	82.1
1990	37	368	96.2	1.6	0.4	58.8
1991	36	366	92.7	1.6	0.4	56.3
1992	15	312	78.4	12.7	3.2	60.2
1993	10	339	85.2	31.6	8.1	67.1
1978-1993	229	312	82.8	4.4	1.1	67.0

\* Including underground water inflow which is equal to 5 km<sup>3</sup>/year

We computed the effect of the dam during 1980-1984 separating the Caspian Sea from the Kara-Bogaz-Gol Bay and the decrease of water outflow from the Sea to the Bay up to 1-2 km<sup>3</sup>/year during 1985-1990. As a result, outflow of the sea water to the Bay was reduced greatly if compared with the conditions of a free water exchange which led to an additional water level rise in the Sea by 3-4 cm/year. The total saving of the sea water due to this anthropogenic factor was equal to about 134 km during 1980-1990, which provided the water level rise by about 35 cm, or about 16% of the present water level rise in the Caspian Sea.

The water level rise since 1978 is explained by climatic factors which determine a change in the water balance ratio towards the increase of the positive components: surface water inflow, mainly from the Volga River, and precipitation onto the surface of the Sea; and towards the decrease of the negative components: evaporation from water surface. A dam across the strait separating the Kara-Bogaz-Gol Bay also stimulated the water level rise in the Caspian Sea.

The presented water balance of the Caspian Sea for 1978-1993 is in a good agreement in case of all its components are determined independently, therefore, the effect of other factors (tectonic, compression of the Earth's crust, etc.), if there are any, is insignificant and it is within the limits of the accuracy of determination of its increments.

The derived long-term data on the water balance components of the Caspian Sea provided the assessment of a statistical dependence of the annual change in the Sea water level upon the major factors which determine this change. As a result, the conclusion was drawn that water inflow to the Sea from the rivers is the major factor which explains water level fluctuations in the Caspian Sea. Correlation coefficient between annual increments of the water level and total water inflow from the rivers to the Sea during 1880-1993 was about 0.80.

A dependence of Sea water level increments upon the amount of precipitation onto the Sea surface appeared to be quite significant. Correlation coefficient computed from the data for 1880-1993 was equal to 0.43.

Determination coefficient between water level fluctuations and evaporation from the Caspian Sea surface during 1940-1993 was equal to 0.30. Annual depth of evaporation, obtained at SOI from the formula which took into account the main processes (13) was used for the computations.

Multiple regression coefficient for water level increment depending on the inflow of river water, precipitation and evaporation from the surface of the Sea for the period of 1940-1993 was equal to 0.85 (Fig. 5).

The presented data show quite convincingly that the effect of the water balance components of the Caspian Sea, inflow of water from the rivers to the Caspian Sea in particular is very significant for the long-term fluctuations of the Sea water levels.

#### **4. Effect of Climatic Factors and of Man's Impact on Sea Water Level Fluctuations**

##### **4.1. General**

The position of the water level in the endorheic Caspian Sea depends on a number of natural and anthropogenic factors, affecting in its basin and on its water area. These are mainly variations of natural climate characteristics explained by the mode of the general circulation in the atmosphere and which determine the moisture and thermal regime in the drainage area, evaporation and precipitation on the water area of the Sea, and development of man's activity in the drainage area affecting the amount and regime of water inflow to the Sea from the rivers. To a certain extent, the water level in the Sea depends on the hydraulic measures on the water area of the Sea, primarily, it concerns water outflow to the Kara-Bogaz-Gol Bay. Moreover, possible variations of the climate factors lead to both, fall and rise of the Caspian Sea water level, meanwhile man's impact in the regions, causing a greater water consumption and reduced total water inflow to the Sea, would inevitably lead to water level fall. During the very last years it was discovered that the anthropogenic change of the global climate resulted from higher concentrations of "green-house" gases in the atmosphere might affect the water balance and water levels of the Caspian Sea; the effect of this change in the near decades may be very great and it should be taken into account at the assessment of water level position in the future.

A development of methods for super long-range computations and forecasts of the Sea water levels primarily requires the assessment of the effect of different natural and anthropogenic factors for the water level fluctuations on the basis of the historical data analysis and the analysis of observation data for a long-term period.

##### **4.2. Effect of Natural Climate Factors**

Natural climate factors are those factors which determine a change of climate on the Earth during many millions, thousands and hundreds of years. Among these factors it is possible to select events external relative to the planet, e.g. change in solar radiation, in the orbit and axis of the Earth's rotation, and events which occur on the planet, i.e. replacement of continents, transformations of the land and sea bottom topograph; volcanic activity, change in the chemical composition of the atmosphere, etc. Climate change during the last millenia occurred at unchanged orbit and axis of the Earth's rotation, unchanged structure of the Earth's surface and permanent solar radiation. According to the opinions of many specialists, most significant climate changes occur during the periods of intensive volcanic activity and variations in the chemical composition of the atmosphere.

Climate changes are displayed not only by air temperature but in the changes of evaporation and precipitation regimes. The effect of natural climate factors for the water level fluctuations in the Caspian Sea is extremely great, which is proved by the data given in Section 1 of the present paper, as well as data in Fig. 6a, where the dynamics of water levels obtained from the data of R.K. Klige (26) are presented for the historic period.

E (cm)

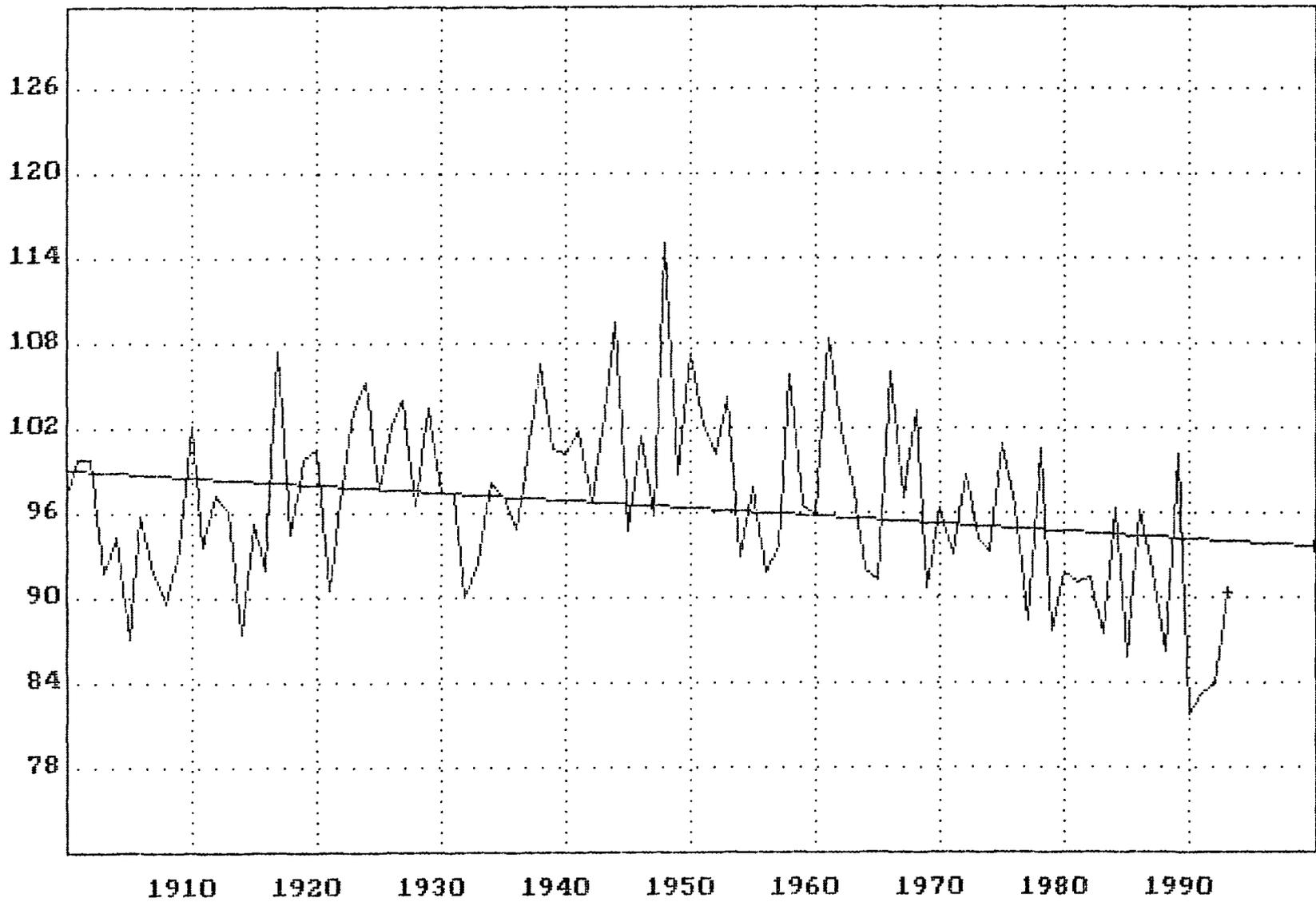
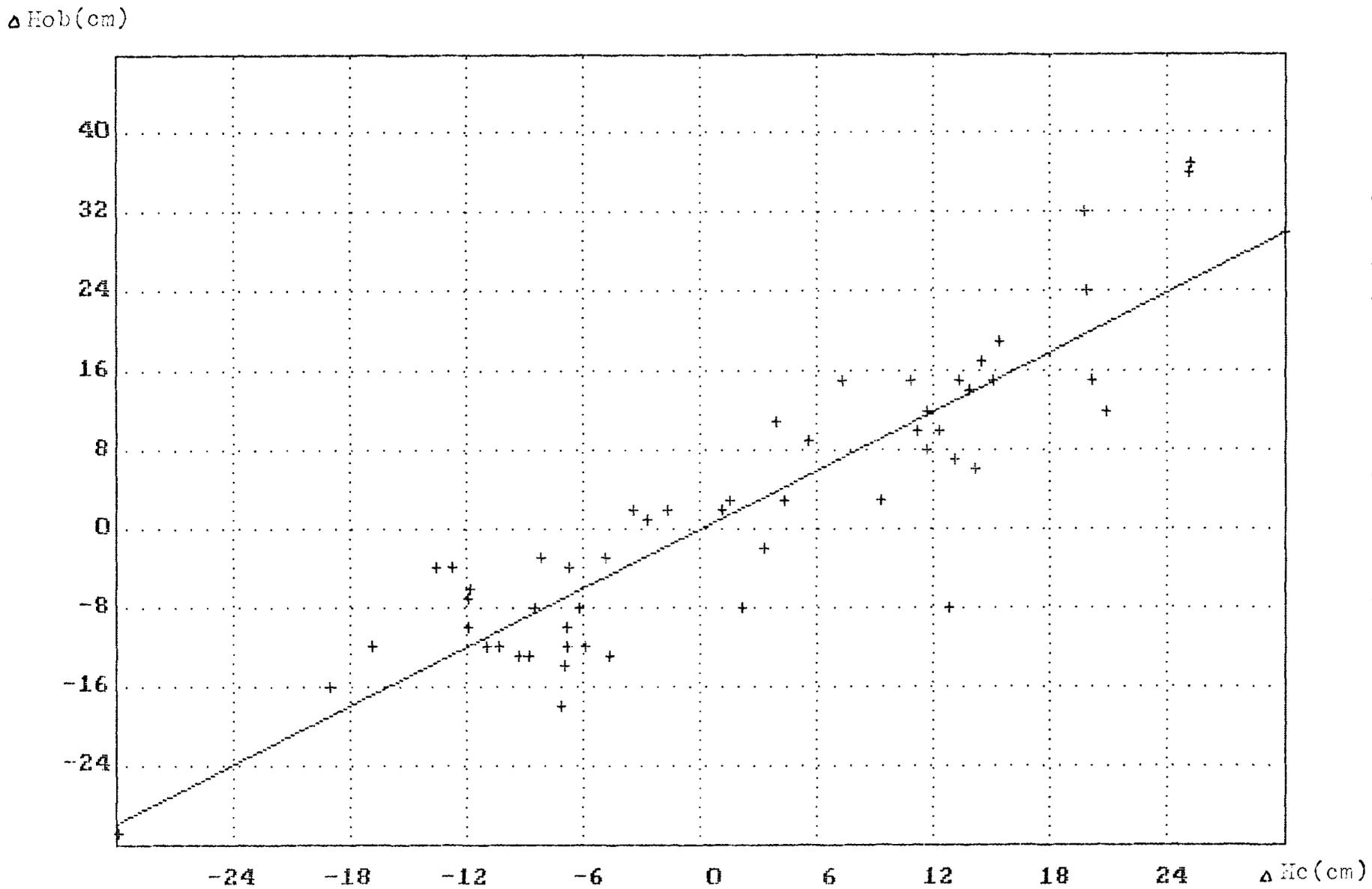


Fig.4. Dynamics of evaporation from the Caspian Sea surface during the period of 1900 - 1993

Fig.5. Relation between observed (Hob.)  
and computed (Hc.) annual increasings of the Caspian Sea levels



In accordance with the presented data, the water level fluctuations are of an evident cyclic nature. During the last 2200 years it is possible to select 7 cycles of higher and lower sea water levels 300-400 years long each. During the periods of low water level the water level marks fell up to -30-33 m (BS); during the periods of transgressions the water level rose up to the level marks at -23-24 m, i. e. the maximum range of level fluctuations due to natural climate factors was about 8-10 m.

According to the data of B.D. Zaikov (Fig. 6b), the range of sea level fluctuations after 1550, also due to climate factors, was 5.5 m. Water level fluctuations in the Sea (according to the data of measurements by instruments) since 1830 are shown in Fig. 2. During the first 100 years of the marked period water fluctuations were insignificant, i.e. the maximum water level was observed in 1882 at the absolute water mark at -25.22 m; the minimum water level was observed in 1925 at the water level mark at -26.69 m, i.e. the maximum range of water level fluctuations did not exceed 1.37 m; these fluctuations were completely affected by climate factors. An intensive water level fall during 1930s by 1.70 m was also explained by about 94% by climate factors, as investigations showed (27).

As noted above, the inflow of the river water to the Caspiar Sea (out of which 84% of the inflow are contributed by the Volga River) plays its most important role in the Caspian Sea level fluctuations.

To discover the effect of climate factors on water inflow to the Sea, and, consequently, on the Sea water level, we have analysed long-term variations of precipitation onto the Volga River watershed. Therefore, we have used data on precipitation averaged for particular Volga basin areas in the zone of runoff formation obtained at the Main Geophysical ObservatioU (MGO) for the period of 1891-1973 and then we have extrapolated these data for the period including 1990. We have used data from 46 meteorological stations. As a result of that analysis, we have discovered that the periods of higher or lower water availability in the Volga River are mainly explained by increased or, consequently, decrease annual precipitation (Table 5).

Table 5 - Total Annual Precipitation in the Zone of Runoff - Formation of the Volga River

Region	1891-1990	1933-1940	1978-1990
Kalininskaya	595	572	637
Permskaya	547	478	585
Bashkirskaya	473	386	524
Kaluzhskaya	616	632	667
Tulskaya	548	532	608
Kostromskaya	580	534	623

A comparison of precipitation for 1933-1940 when water flow from the Volga River was extremely low and for 1978-1990 when river outflow was higher with long-term precipitation norm is quite significat. During 1930s total annual precipitation in the zone of the Volga runoff formation (Upper Volga, Kama and Oka basins) reduce a by 20-70 mm. On the contrary, at the end of 1970s the total annual precipitation in the Volga basin increased by 40-60 mm. This great variability of precipitation was the reason of runoff anomalies in the Volga River, and, as a result, it caused sudden water level fluctuations in the sea. In future, the effect of natural climate factors on the water balance components and on the water level in the endorheic Caspian Sea would be significant; and this is the main difficulty for making a long-range forecast.

#### 4.3. Effect of Man's Activity

The effect of man's activity on the Caspian Sea regime is mainly displayed in variable water inflow to the Sea due to different arrangements on the watershed and water projects in river channels, i.e. irrigation, drainage, agrotechnical measures, forest cut and forest planting, construction and operation of reservoirs and ponds, industrial and municipal water consumption. The quantitative assessment of man's impact on river runoff is a very complicated problem, firstly, because a great number of anthropogenic factors affect the watershed simultaneously (often, they affect in opposition directions); secondly, changes caused by man's impact are oriented and they are super-imposed on

the natural river runoff variations; the range of these variations usually exceeds the amount of induced changes; thirdly, reliable data are not always available on a complete account of all water diversions and waste discharges in the basin, as well as information characterizing the time, scales and rates of different projects within the basin.

Multipurpose investigations of the SHI on the assessment of the effect of different types of man's activity on river runoff in the Caspian Sea region and water inflow to the Sea are made since the beginning of 1970s; the last more accurate assessments were made for the Caspian Sea area during 1993-1995.

The dynamics of river inflow to the Caspian Sea under the effect of a variety of man's impacts are given in Table 6. These data were obtained by using two independent approaches, i.e statistical approach and water balance approach. The statistical approach was applied for an integral assessment of anthropogenic changes in runoff by studying long-term variations of river runoff from observational data available in combination with the analysis of natural runoff-forming factors in the basin. The water balance approach is based on the account of direct water diversions for economic needs and on the study of water balance components immediately on the areas of watersheds where the conditions of runoff formations are changed because of some type of man's activity. Moreover data of experimental and field studies were widely applied for the water balance approach.

Table 6. Changes in Water inflow to the Caspian Sea under the effect of man's impact

Sea, rivers	Conventional natural inflow km <sup>3</sup> /year	Years					
		1936-40	1946-50	1956-60	1966-70	1976-80	1986-90
Caspian Sea including:	298	6.3	10	33	22	38	40
Volga	240	4.8	6.3	26	13	21	25
Ural	9.3	0.2	0.6	1.2	1.5	2.3	2.
Kura	18.0	0.2	1.0	1.6	1.2	3.0	4.
Terek and Sulak	13.4	0.4	0.9	2.2	3.4	3.7	3.

Particular methods for the assessment are described in details in (26, 27).

Before 1940 water inflow to the Sea was practically natural, the effect of anthropogenic factors was estimated to be equal to 2.2% of the normal inflow under natural conditions. A sudden decrease of inflow began since 1950s mainly due to reduced water discharge from the Volga River, - that was the time when a filling of very large system of Volga-Kama reservoirs was started. At present, the reduced water inflow to the sea due to man's impact is about 40 km<sup>3</sup>/year, or 13% of total normal inflow. A major portion of the anthropogenic decrease of water inflow to the Sea is contributed by the Volga River basin. The effect of individual types of man's activity for reducing water inflow to the sea during the study period is different. During 1956-1975 a construction and operation of reservoirs were the basic factors of man's activity which intensified the decrease of water discharge to the Sea; during 1980s the major water losses were caused by irrigation.

It is quite natural that inflow change to the Sea because of man's activity stimulated the change in the water level position in the Sea. Computations made on the basis of the water balance of the Sea in greater details for each year show (28) that most intensive water level fall in the Sea occurred during 1932-1940 (with water level fall by 1.68 m) is explained by a sudden decrease in the income terms of the water balance caused by the natural climate factors effect: the water inflow to the Sea during that period of time was equal to 77% only, meanwhile precipitation equaled 90% of the norm at the total evaporation (evapotranspiration) being close to normal. All these factors explained the water level fall in the Sea by about 1.58 m; the remaining water level fall by 0.10 m may be related to the effect of man's activity in the basin. Later the effect of man's activity on the water level fluctuations in the Sea becomes most impressive (Fig. 2).

If river runoff to the Caspian Sea were not changed under man's impact, then, since 1955 a stable phase of the water level rise would begin; by 1972 the mean water level mark would be by 1 m higher than the observed value; by 1990 the water level would be by 1.6 m higher above the observed level.

Man's impact not only caused the decrease of the total annual water inflow to the Caspian Sea but it introduced great changes in streamflow distribution during a year. This caused changes in the nature of water level fluctuations in the Caspian Sea during a year, which is evident from the graph presented in Fig. 7, where mean water level in the Sea is distributed during a year for the period of 1941-1945, when river runoff to the Sea was practically undisturbed by man's impact, and for the period of five years (1968-1972) during which the effect of man's activity was quite significant. Major changes occurred in the earlier phase of water level rise and fall during the yearly cycle (by 15-40 days) and in the maximum water level values. In general, it was the result of an increased runoff volume in winter and decreased spring snowmelt runoff in the Volga River resulted from runoff control by the Volga-Kama system of reservoirs.

Not only man's activity on the watershed, but man's activity on the water area of the Caspian Sea may affect the water level of the Caspian Sea. As mentioned above, the dam made across the strait to separate the Kara-Bogaz-Gol Bay from the Caspian Sea caused some water level rise in 1980 which was about 3.0-3.5 cm/year.

Anthropogenic factors would certainly affect water level fluctuations in the Caspian Sea in the future, too; therefore, we would face a complicated problem of making a reliable long-range forecast of river runoff changes to predict water inflow to the Sea with the account of future projects.

It should be noted that a great uncertainty in the prospects for a future economic development and water consumption takes place because of a separation of the FSU into independent states and because of complicated socio-economic conditions in these states at present. Therefore, assessments made for the future are to a great extent of an expert nature.

We have estimated approximate values for a probable reduction of the total water inflow to the Caspian Sea from the rivers under the effect of different factors of man's activity before 2020. In accordance with the obtained results we can expect a stabilization of the irretrievable water consumption in the basin during 1996-2000, therefore, the decrease of water inflow to the Caspian Sea would be about 40 km<sup>3</sup>/year. Then, irretrievable water losses from river basins would be greater, therefore, water inflow to the Sea would be less by 44 km<sup>3</sup>/year in 2010 and by 47 km<sup>3</sup>/year in 2020. These values correspond to mean climate conditions and to a stationary climate situation.

These approximate data should be revised in future.

## **5. Methods for Predicting Water Levels in the Caspian Sea**

The available data on the water balance on the Caspian Sea and on the changes in river water inflow to the Caspian Sea under the effect of man's activity make it possible to conclude that the sea water level is sensitive to variations of the water balance components very much, and to water inflow in particular; secondly, that the effect of man's activity in the Caspian Sea watershed is demonstrated by the water level fluctuations and this effect would be displayed in the future as well. Moreover, if natural variations of the sea water balance components might produce both water level rise and fall, the effect of man's activity explains the trend in the water level fall. It means, that a reliable assessment of the future water level position in the Caspian Sea requires a forecast of the water level fluctuations under the effect of climate factors and the effect of the outlined man's activity in the region should be estimated.

Fig. 6. Secular variations of the Caspian Sea levels  
(according to Zaikov B.D.)

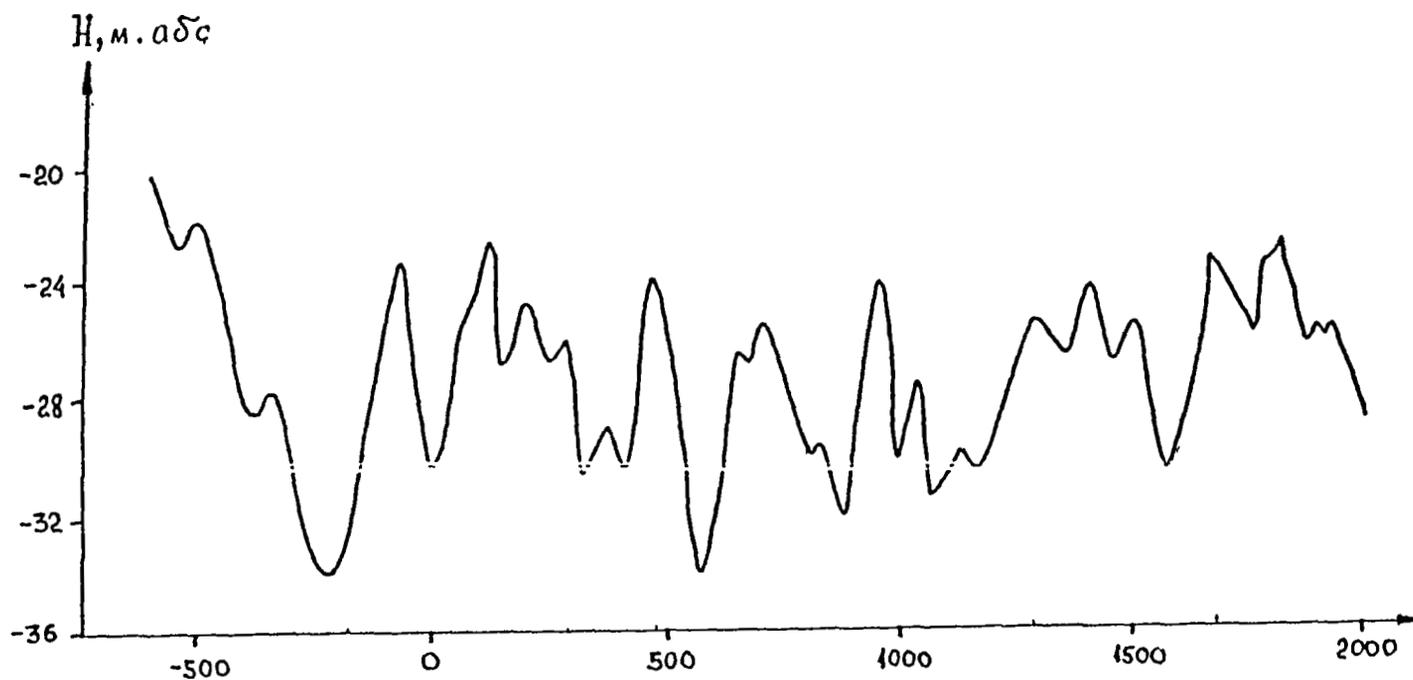
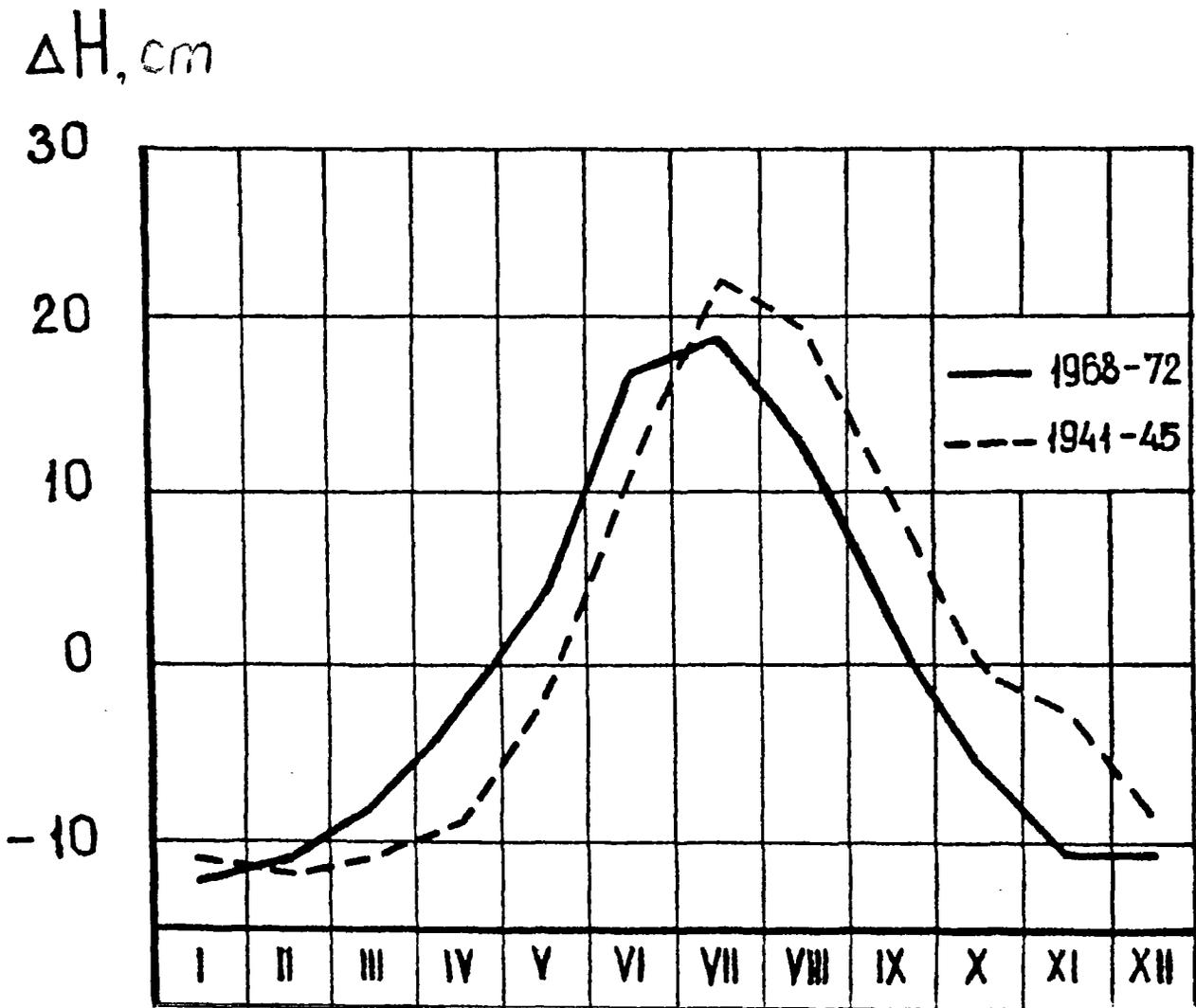


Fig. 6a.



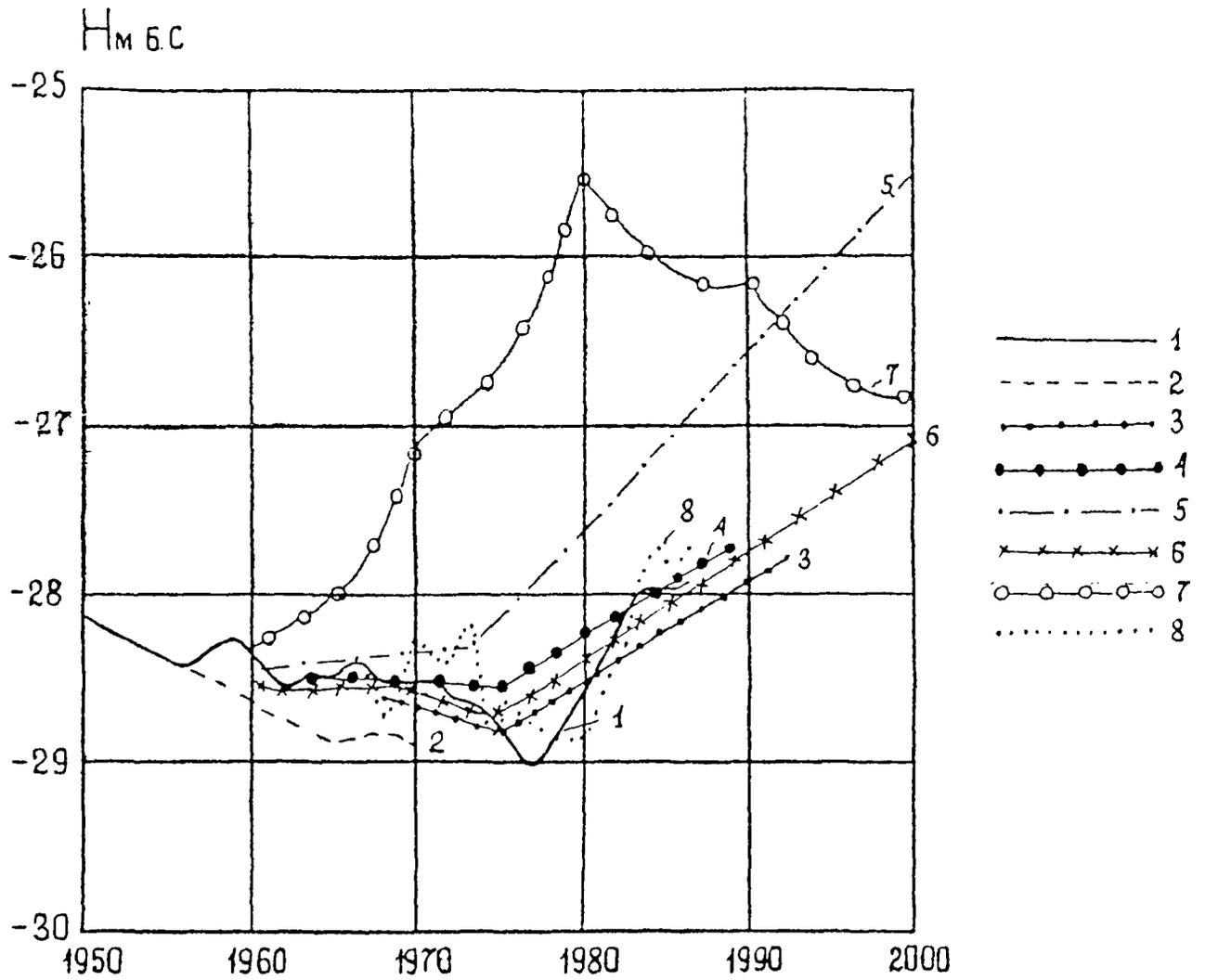
Fig. 6b.

Fig. 7. The mean yearly distribution of the Caspian Sea levels for the five-year periods of 1941-1945 and 1968-1972



**Fig. 8. Result of super long-range forecasts of the Caspian Sea water levels under the effect of natural climate variations, according to the assessment of different scientists:**

- forecasts:
1. Observed level
  2. Appolov B.A.
  3. Afanasjev A.N.
  4. Soskin I.M.
  5. Antonov V.S.
  6. Shliamin B.A.
  7. Arkhipova E.G. et al.
  8. Smirnova K.I.



The first problem is very difficult, i.e. it is extremely difficult to predict natural water level fluctuations in the Sea 10-15 years in advance and even longer. Numerous publications are available on this problem; they were mainly written during 1960S-1970s, where mean level parameters were estimated for the future or water level fluctuations for each year were predicted from 5 to 30 years in advance. All methods for a super long-range forecasting of the water level in the Caspian Sea are based on the following principles:

- on the establishing different dependences of level parameters upon solar radiation, most often expressed by Wolf numbers - B.A. Appolov (3), A.N. Afanasiev (5), I.M. Soskin (24), M.S.Eigenson (3), E.G.Arkipova et al. (4).
- on the establishing relations between water level fluctuations and various forms of atmospheric circulation, most often expressed as indices of Vangengeim & Vitels N.A. Belinsky and G.P. Kalinin (7), V.S. Antonov (2), A.A. Girs (14), K.I. Smirnova (22)
- on the discovery of cycles in the series of long-term water level fluctuations and extrapolation of these cycles for the future - B.A. Shliamin (27).

The results of these forecasts are given in Fig. 8.

As it follows from the data in Fig. 8, the results of the forecasts are ambiguous and even contradictory. It should be noted, however, that all these forecasts were made during 1960s-1970s, and most of these forecasts marked a trend in water level rise during 1970-2000. At present different viewpoints are available on the position of the Sea level in the near 10-20 years; these viewpoints are based on these types of forecasts and it is hardly possible to use these forecasts for decision-making on the protection of the sea coast against water overflow and formation of shallow water table around the flooded areas.

Analysing methodological approaches and results of the climate forecasts for the sea water level, it should be noted that these forecasts make a part of a tremendous problem of super-long-range forecasting of the averaged climate conditions over vast areas (in this particular case it is the major portion of the European territory of Russia and FSU making the Caspian Sea drainage area); this problem is far from being solved and reliability of the predicted water levels for this remote future is very low. Many scientists note, that correlation dependences between water levels in the Sea and characteristics of the atmospheric circulation contain systematic errors, they are variable and do not provide effective forecasts for a long time period. Inadequacy of reliable methods for predicting the forms of atmospheric circulation is another very important disadvantage of this approach, because this forecast is made on the basis of the analogy method, which is quite conventional (as many forecast-makers assume), because the atmospheric processes variations in the past may be quite different in the future. It should be added, that anthropogenic climate change during the nearest decades would greatly affect the nature of the processes of the atmospheric circulation (19).

The use of the so-called Sun-Earth relations for long-range forecasts is not yet reliable because these relations have no sufficiently validated physical and experimental basis which greatly reduces the truth of these forecasts; besides, these relations are not very stable. This instability is displayed in the results of correlative dependences for the Caspian Sea water levels upon indices of the solar activity and atmospheric circulation (10).

Investigations made at the SHI show that the results of super-long-range forecasts should be treated with a great care even if they are based on the relations with high correlation coefficients. Depending on the fact what long-term period was selected for the analysis and what factors are analysed, it is possible to draw absolutely different and even contradictory conclusions on the future water level fluctuations in the Sea.

These conclusions do not mean that the problem of super-long-range forecasting of water levels in endorheic water bodies is hopeless. Relations between water balance components of the Sea and the factors of space and geophysical origin are probably more complicated; the discovery of these relations and their physical interpretation are difficult and this problem is not yet solved.

Another approach to the assessment of the position of the Caspian Sea level is its probabilistic computation (I, 6, 8, 20).

The authors of these publications show quite convincingly that even in case of the time-stable norms of the basic water balance components of the Sea, i.e. total river water inflow to the Sea and depth of conventional evaporation, the water level fluctuations may be quite significant in case of their random variations at about average values. Appropriate methods have been developed for the computation of statistical characteristics of the water level.

The analysis of the results of probabilistic forecasts for the Caspian Sea water levels made by different authors during 1970s' provided the following. At mean hydrometeorological conditions the sea water level fall was expected. The intensity of the level fall was determined by the accepted project data on irretrievable water losses from the Caspian Sea watershed. At present it is possible to state, that the perspective indices for total and irretrievable water consumption, developed by different institutions during 1970s, appeared to be overestimated greatly, which affected the results of water level computations. It should be also noted that in some publications the decrease of water outflow to the Kara-Bogaz-Gol Bay due to the dam construction is not taken into account. Thus, the uncertainty of the data on future water consumption and impossible prediction of the accurate date of large water projects implementation is one of the reasons of uncertain forecasts of the water level.

In conclusion it should be noted, that water level rise by 2.3 m during 1978-1993 goes beyond the 95% confidence probability and it should be regarded as an event of an extremely rare frequency.

A validated prediction of future probable water level fluctuations requires, on our opinion, a multipurpose approach with the account of historical data on the water level fluctuations, present data and data on the expected anthropogenic climate change and a development of an adequate mathematical model of the water balance of the Caspian Sea.

## **6. Research Problems on the Development of Method for Prediction (Computation) of the Water Level in the Caspian Sea**

Super-long-range prediction (computation) of the Caspian water level for the future 20-30 years requires a forecast of changes in water balance components under the effect of climate factors, a forecast of changes in the river water inflow under the man's impact, as well as resulted from possible hydraulic structures affecting water outflow to the Kara-Bogaz-Gol Bay, and probably to other bays too.

Thus, the forecast of the Caspian Sea water level should be regarded as a part of the more general problem of predicting climate conditions on the Caspian Sea watershed, and this problem is not yet solved.

Proceeding from the above, the following studies should be given the first priority for the assessment of the water balance and water level in the Caspian Sea for the future:

- (a) Development of most probable scenarios of climate conditions in the Caspian Sea area during nearest decades.

Within the framework of these studies, it is most promising to use two simultaneous approaches for the modelling of climate and for making the climate forecast; the first approach is based on the use of paleoclimate reconstructions, the other approach is based on mathematical models of general circulation.

First, it is necessary to generalize, to analyse and to compare the available climate scenarios for the Caspian Sea area with the used of the above approaches, to establish the rate of correspondence of the climate conditions during the present water level rise in the Caspian Sea to these scenarios, to provide a physical explanation for the trends in precipitation and evaporation from water surface observed in the basin, and to evaluate their random and deterministic components, etc.

These studies should result in the assessment of basic climate characteristics (precipitation and air temperature in particular) for the study area for the nearest several decades.

- (b) Assessment of river water inflow to the Caspian Sea, evaporation from the Caspian Sea surface and precipitation under most probable climate conditions.

Here it is necessary to develop adequate mathematical models describing water exchange in "*climate - water resources*" and "*atmosphere - sea surface*" systems, oriented to the use of predicted climate characteristics as input data.

These studios should result in a quantitative assessment of sea water balance components for the predicted climate conditions.

- (c) Forecast of river water inflow changes under the influence of factors of man's activity, as well as the results of probable hydraulic structures on water outflow to the Kara-Bogaz-Gol Bay.

The solution of the first problem requires a development of the most realistic scenario for the evolution of principal water-consuming branches of the national economy in the basins of rivers discharging to the Caspian Sea, and a quantitative assessment of irretrievable runoff losses for different economic needs with the account of predicted climate conditions.

Taking into account that water outflow from the Caspian Sea to the Kara-Bogaz-Gol Bay is quite significant for the sea water level fluctuations (during the recent decade the outflow value varied from 0 to 31.6 km<sup>3</sup>/year), the primary objective is to estimate the conveyance capacity of the strait by means of experimental measurements and to establish relations between outflow and position of the Caspian water level, according to the present conditions. It is also necessary to follow the dymmics of changes in the water area of the Bay during the last years from satellite images.

- (d) Development of mathematical model of the Caspian Sea water level fluctuations and its forecasting (computation) for the nearest 10-30 years with the account of man's impact on the watershed area and on the water area of the Caspian Sea.

It is supposed that the water balance equation of the Caspian Sea would be used as the model of water level fluctuations in the Sea. This equation is nonlinear and nonstationary. A method of statistical tests may be applied for the solution of this equation. Moreover the appropriate models of water inflow from the rivers, evaporation and precipitation (or conventional evaporation) obtained for the most probable climate scenarios would be taken as input processes.

REFERENCES (in Russian)

1. Alexeev G.A. Probable change in the Levels of the Caspian and Aral Seas. "Meteorology and Hydrology", 1947, No.4, p.48-50.
2. Antonov V.S. Problem of the Caspian Sea water level and runoff of northern rivers. - "Trudy AANII", 1963, vol.253, p.232-248.
3. Appolov B.A., Alexeeva K.I. Prediction of the water level in the Caspian Sea. "Trudy Okeanograf. komissii AN SSSR", 1959, vol. 5, p.63-78.
4. Arkhipova E.G., Kriukov V.F., Moloshnikova V.N. Probable variations of water level changes and variations of other components of the hydrological regime of the Caspian Sea. - "Trudy GOIN", 1972, vol.115, p.5-17.
5. Afanasiev A.N. Variations of hydrometeorological regime on the USSR territory. Moscow, "Nauka", 1967, 230 pp.
6. Bagrov N.A. On water level fluctuations in endorheic lakes. "Meteorology & Hydrology", 1963, No. 6, p.41-46.
7. Belinsky N.A., Kalinin G.P. On predicting water level fluctuations in the Caspian Sea. - "Trudy GUGMS", 1946, ser.4, vol. 37, p.18.
8. Budyko M.I., Yudin M.I. On water level fluctuations in lakes without outflow. - "Meteorology & Hydrology", 1960 No.8, p.15-19.
9. Varushchenko S.I., Varushchenko A.N., Klige R.K. Change in the regime of the Caspian Sea and in endorheic water bodies during paleotime. Moscow, "Nauka", 1987, p.240.
10. Georgievsky V.Yu, Computations and forecasts of changes in water level of the Caspian Sea under the effect of natural climate factors and man's impact. - "Trudy GGI", 1978, v.255, p.94-112.
11. Georgievsky V.Yu. Water balance of the Caspian Sea from observation data. - "Trudy LGMI" 1982, vol.79, p.129-136.
12. Georgievsk Jr V.Yu., Ezhov A.V. Prospects for Joint control of water and salt balances of the Caspian Sea and the Sea of Azov. Proc. of the Vth All-Union Hydrological Congress, 1990, vol. 4, p.178-185.
13. Hydrometeorology and hydrochemistry of seas. Vol.VI, the Caspian Sea, issue 1. St. Petersburg, Gidrometeoizdat, 1992, p.359.
14. Girs A.A. Long-term variations of the atmospheric circulation and long-range hydrometeorological forecasts. - Leningrad, Gidrometeoizdat, 1971, 280 pp.
15. Zaikov B.D. Water balance of the Caspian Sea in connection with the reasons of its water level fall. Trudy NIU GUGMS, 1946, ser. 4, vol.88, 19 pp.
16. Caspian Sea. - Moscow, Izd-vo MGU, 1969, 261 pp.
17. Kritsky S.N., Korenistov D.V., Ratkovich D.Ya. Water level fluctuations in the Caspian Sea. - Moscow "Nauka", 1975, 157 pp

18. Panin G.N. Evaporation and heat exchange of the Caspian Sea. - Moscow, "Nauka", 1987, 88 pp.
19. Future changes in climate. Leningrad, Gidrometeoizdat, 1991, p.272.
20. Privalsky V.E. On probabilistic forecast of water balance components and water level fluctuations in the Caspian Sea. "Meteorology & Hydrology", 1976, No. 5, p.70-76.
21. Ratkovich D.Ya., Zhdanova I.S., Privalsky V.E. On the problem of water level regime in the Caspian Sea. - "Water Resources", 1973, No. 3, p.45-69.
22. Smirnova K.I. Water balance and long-range forecast of the water level in the Caspian Sea. "Trudy Gidromettsentra SSSR", 1972, vol. 94, 123 pp.
25. Present and future water balance and long-range forecast of the Caspian Sea water level. - "Trudy Gidromettsentra SSSR", 1972, vol. 94, 123 pp.
24. Soskin I.M. Caspian Sea water level and solar radiation. "Trudy GGO", 1959, vol. 89, p.72-82.
25. Shilo N.A., Krivoshei M. I. Interrelations between water level fluctuations in the Caspian Sea and tensions in the Earth's crust. - "Vestnik AN SSSR", 1989, No. 6, p.83-90.
26. Shiklomanov I.A. Effect of man's activity on river runoff. - Leningrad, Gidrometeoizdat, 1989, 334 pp.
27. Shiklomanov I.A. Hydrological aspects of the Caspian Sea problem. - Leningrad, Gidrometeoizdat, 1976, 78 pp.
28. Shiklomanov I.A., Georgievsky V.Yu. Water inflow and water levels of the Caspian Sea and their changes under the influence of climate factors and man's activity. - "Water Resources", No. 5, 1981, p.5-19.
29. Shiklomanov I.A., Kozhevnikov V.P. Runoff losses from the Volga-Akhtuba floodplain and from the Volga delta and their changes under the effect of man's activity. "Trudy GGI", 1974, vol. 208, p.60-79.
30. Shiklomanov I.A., Smirnova L.E. Assessment of man's impact on runoff of large Caucasian rivers. - "Trudy GGI", 1973, vol. 206, p.92-122.
31. Eigenson M.S. The future of the Caspian Sea. Problems of the Caspian Sea - In: "Vsesoyuz. Soveshchaniya po probleme Kaspiyskogo moria". Izd. AN AzSSR, 1963, p.24-28.

**ISOTOPE STUDIES OF CASPIAN SEA LEVEL RISE IMPLICATIONS\***

V.I. Ferronsky, V.S. Brezgunov, V.V. Romanov, L.S. Vlasova  
Water Problems Institute of the Russian Academy of Sciences  
Moscow, Russia,

V.A. Polykov, A.F. Bobkov  
Research Institute of Hydrogeology and Engineering Geology  
Zeleny, Moscow Region, Russia

**ABSTRACT**

**ISOTOPE STUDIES OF CASPIAN SEA LEVEL RISE IMPLICATIONS**

After more than 40 years of continuous decline since 1978 the Caspian Sea level is rising and to the end of 1994 its amplitude approached 2.5 m. The nature and the mechanism of perpetual sea level variations are unknown. But in this particular case it was noticed from the observation that the sea level rise is accompanied by increase of river runoff from the catchment area and decrease of evaporation from the sea surface. In order to understand the sea level rise implications in water dynamics isotope studies were undertaken by periodical sampling of sea, river and precipitation water. By comparison of oxygen isotopes and salinity distribution it was found that the pattern of the river and sea water mixing is changing. Residence time of water masses of the North Caspian Sea and the main water balance characteristics were determined using oxygen isotope-salinity diagram analysis. The problem of vertical mixing process of cold bottom and warm surface water in the Middle and the South depressions was studied on the basis of tritium data of 1983, 1991 and 1994 sampling cruises. Due to increase of the river runoff the cold bottom water rise was intensified. Consequently the surface layer temperature dropped and evaporation decreased. This feedback effect of water dynamics in sea level variation was derived from the study. Quasi-periodic hydrotroilite layers in the sea bottom core sediments were discovered, Preliminary isotope and chemical analysis show that the hydrotroilite ( $\text{FeS} \cdot n\text{H}_2\text{O}$ ) is a promising indicator of sea level variation in the past.

---

\* The paper was presented to the International Symposium of the IAEA in March 1995, Vienna

## 1. INTRODUCTION

Caspian Sea is the largest closed basin whose water table is of more than 25 m below the oceans level. The Sea was separated from the ocean together with Mediterranean and Black Seas about 5 Myr ago during the Alpine orogenesis. The morphometric and hydrologic parameters of the Sea are reported in Table 1 (1) and Figure 1.

The Sea is situated in the arid zone with 0.19 m/yr of precipitation and 0.96 m/yr of evaporation. But the catchment area which is represented mainly by Volga River basin, is located in the humid region. In this connection the sea-catchment system as a whole and its water input (runoff plus precipitation) to evaporation ratio in particular are extremely sensitive to long and short-periodic climate variations within the system basin. This climate sensitivity is developed first of all in continuous variation of the sea level which is an objective measure of the water balance.

Palaeogeographic data shows that during the last 10 Kyr the amplitude of the sea level varied between -20 and -35 m relative to the ocean level. Since 1837 within the period of instrumental observation the amplitude reached to 4 m. The present day rise of the sea level started in 1978 and reaches now the mark of -26.5 m. The dynamics of the sea level and some other hydrological parameters are shown in Figure 2.

The nature and the mechanism of the sea level variation is the most important scientific problem which is of great practical interest of riparian countries. There is no acceptable theory or any empirical approach to predict the phenomena rising economical and social problems. Isotope studies of water dynamics and bottom sediments are a new tool of Caspian Sea investigation.

TABLE I. BASIC CHARACTERISTICS OF CASPIAN SEA (1977)

Latitude		36°33' - 47°07'N
Longitude		46°43' - 54°03'E
Surface		378400 km <sup>2</sup>
Volume		78100 km <sup>3</sup>
Length	(50°00' N)	1030 km
Width, max.	(45°30' N)	435 km
Width, min.	(40°30' N)	196 km
Depth of the North part, max/mean		25/4.4 m
Depth of Middle part, max/mean		782/192 m
Depth of South part, max/mean		1035/342 m
Catchment area, total		3.5.10 <sup>6</sup> km <sup>2</sup>
Catchment area of Volga River		1.38.10 <sup>6</sup> km <sup>2</sup>
Precipitation, mean	(1900-1982)	0.19 m/yr
River runoff	(1900-1982)	0.77 m/yr
Evaporation, mean	(1900-1982)	0.97 m/yr
Sea level relative oceans	(Jan. 1995)	-26.5
Temperature of surface water, mean ann.		13° C
Temperature of bottom water, mean ann.		5.5° C
Salinity, mean ann.		13‰
Humidity over the sea, mean ann.		80%

## 2. WATER EXCHANGE IN THE NORTH CASPIAN SEA

General water circulation pattern of the sea is as follows. Because of Volga River runoff (80% of total) and due to deflecting role of the Coriolis force, the major water stream moves along western coast from the north and back along eastern coast from the south. Some portion of the flow diverts in each part of the sea in counterclock-wise direction forming three cyclonic streams. Upwelling of cold bottom water is developed along eastern coastal area.

Isotope studies of sea water dynamics were periodically undertaken since 1978. Cruises for water sampling in northern part of the sea were organised in 1980, 1982-1984 and 1990-1991.

It was found that Middle Caspian Sea water is characterized by mean value of  $\delta^{18}\text{O} = -1.7\text{‰}$  and salinity of  $S = 13\text{‰}$ . The water of Volga and Ural Rivers shows mean value of  $\delta^{18}\text{O} = -13\text{‰}$ , and annual mean value of precipitation near Astrachan just at the mouth of Volga River is  $\delta^{18}\text{O} = -10\text{‰}$  with zero salinity.

In the case of simple model of the sea and river water mixing all the experimental points should lie along the straight line of the salinity versus  $\delta^{18}\text{O}$  diagram with co-ordinates defining by expressing  $\delta^{18}\text{O} = 0.87S - 13$ . In reality because of evaporation freezing and melting of ices the sea water is enriched in  $^{18}\text{O}$  and salinity and all the experimental points are appeared above the mixing line (Figure 3). These processes lead to different relation between  $\delta^{18}\text{O}$  and  $S$  from that of a linear correlation (2).

Figure 3 shows experimental data of 1982 sampling campaign in North Caspian Sea. Practically all the points corresponding to the sea water lie above the fresh-sea water mixing line. As a quantitative characteristic of the deviation from the mixing point on  $\delta^{18}\text{O}$ - $S$  diagram, the parameter  $h = \delta_{\text{ex}} - \delta_p$  is taken, where  $\delta_p$  is the isotopic composition of fresh water,  $\delta_{\text{ex}}$  is the value of  $\delta^{18}\text{O}$  obtained from the intercept of the ordinate axis with the straight line passing through the given point and the point of the water mass in shallow closed basin and may be expressed in the form

$$h = \delta_{\text{ex}} - \delta_p = \frac{\delta_p Q_p - \delta_e Q_e}{Q_p - Q_e} - \delta_p = \frac{Q_e}{Q_p - Q_e} (\delta_p - \delta_e) \quad (1)$$

where  $Q_p$  is the quantity of fresh river water that enters into the mixture,  $Q_e$  is the quantity of water that evaporated before sampling time and  $\delta_e$  is the average isotopic composition of the evaporated water.

The expression for the water balance is

$$Q = Q_p + Q_{\text{mic}} - Q_e, \quad (2)$$

where  $Q_{\text{mic}}$  is the quantity of the mean Middle Caspian Sea saline water that enters into the mixture.

The salinity of the mixture is described as

$$S = \frac{Q_{\text{mic}}}{Q} \cdot S_{\text{mic}} \quad (3)$$

where  $S_{\text{mic}} = 13\text{‰}$  is the mean salinity of the Middle Caspian Sea water.

It follows from (1), (2) and (3) that

$$\frac{Q_e}{Q} = \frac{h (1 - S/S_{\text{mic}})}{\delta_p - \delta_e} \quad (4)$$

Taking into account that for the North Caspian Sea  $\delta_p = -13\text{‰}$ , then

$$\delta_e = \frac{\delta_q \alpha - \delta_v H - \epsilon}{1 - H} \quad (5)$$

where  $\delta_q$  is isotopic composition of the evaporated liquid phase,  $\delta_v$  is isotope content of the vapour above the mixture,  $H$  is the relative humidity,  $\alpha$  and  $\epsilon$  are fractionation factors depending on water temperature and humidity.

For the closed water system the value of  $\delta_q$  and  $\delta_e$  do not increase indefinitely, but only until the water body reaches steady isotopic state, when evaporation is equal to in-flow and  $\delta_e = \delta_p$ . The steady state stage is determined by isotopic content equal to  $\delta_q^s$ .

Isotopic composition of Middle Caspian Sea water may characterise steady isotopic state of closed water basin in the given climatic conditions, that is  $\delta_q^s = \delta_{mic}^s = -1.7\text{‰}$ ,  $\delta_e^s = \delta_p$  and  $\delta_e^s - \delta_e = \delta_p - \delta_e$ . It follows from these relations and expression (5) that

$$\delta_p - \delta_e = \frac{(\delta_q^s - \delta_q)}{1 - H} = \frac{\delta_{mic}^s - \delta}{1 - H} \quad (6)$$

The value of  $\alpha$  is close to unity and weakly dependant on the real temperature variation (at 0°C  $\alpha = 1.011$ , and at 20°C  $\alpha = 1.009$ ). In this connection expression (4) may be rewritten, in the form

$$\frac{Q_e}{Q} = \frac{h(1 - S/S_{mic})(1 - H)}{\delta_{mic}^s - \delta} \quad (7)$$

The values of  $Q_e/Q$ ,  $Q_p/Q$ ,  $Q_e/Q_p$  and  $Q_p/Q_{mic}$  ratios are determined by using combination of (2), (3) and (7). These ratios are elements of water balance of the North Caspian Sea areas, were calculated on the basis of measurements of 1982, 1984 and 1990 water samples. The calculated results are presented in Table 2. Three water areas are divided on the basis of isotope data between the longitudes of 49°E and 50°E.

TABLE 2. EXPERIMENTAL AND CALCULATION DATA OF THE NORTH CASPIAN SEA WATER BALANCE CHARACTERISTICS (1982-1990 CRUISES)

Sampling time	Area	n	S, ‰	$\delta_{180}$ , ‰	h, ‰	$Q_e/Q$	$Q_p/Q$	$Q_e/Q_p$	$Q_p/Q_{mic}$
May-June 1982	I	8	8.35	-5.2	1.2	0.037	0.40	0.09	0.62
	II	17	7.87	-5.35	2.06	0.066	0.46	0.14	0.76
	III	10	9.35	-3.8	4.1	0.164	0.44	0.37	0.61
	I+II+III	36	8.40	-4.8	2.45	0.084	0.43	0.196	0.665
Sept.-Oct. 1982	I	14	9.90	-3.4	4.2	0.147	0.38	0.39	0.50
	II	17	8.68	-4.1	4.4	0.152	0.48	0.32	0.72
	III	12	9.90	-3.1	5.8	0.247	0.49	0.50	0.64
	I+II+III	43	9.42	-3.6	4.7	0.17	0.44	0.39	0.61
1982 Mean	I	22	9.13	-4.3	2.7	0.085	0.385	0.22	0.55
	II	34	8.28	-4.7	3.2	0.107	0.47	0.23	0.73
	III	22	9.62	-3.45	5.0	0.2	0.46	0.43	0.02
	I+II+III	78	8.91	-4.2	3.6	0.125	0.55	0.20	0.64
August 1984	I	14	8.46	-4.8	2.2	0.074	0.415	0.18	0.64
	II	7	7.68	-5.0	3.1	0.115	0.525	0.22	0.89
	III	22	8.06	-4.4	4.3	0.182	0.56	0.325	0.90
	I+II+III	43	8.20	-4.6	3.4	0.130	0.50	0.26	0.79
August 1990	I	10	8.76	-4.8	2.5	0.097	0.505	0.19	0.85
	II	10	8.00	-4.35	3.7	0.16	0.545	0.29	0.89
	III	14	6.25	-4.25	5.6	0.34	0.86	0.395	1.80
	I+II+III	34	7.20	-4.4	4.2	0.21	0.66	0.32	0.2

Here n is measurement frequency, S is salinity, h is isotope effect of evaporation of mixed water,  $Q_e$ ,  $Q_p$ ,  $Q_{mic}$  and Q are amount of evaporated, river, mean and total water accordingly.

Relative loss of water  $Q_e/Q$  in the studied shallow basin depends on evaporation velocity and residence time of water. If one takes constant value of evaporation velocity for whole the northern basin then the ratio of  $Q_e/Q$  for eastern and western parts depends only of the residence time. It follows from the calculations, that average value of  $Q_e/Q$  for area III (eastern part of the sea) in 1982 by 2.45 and in 1990 by 3.5 times higher of that for area I (western part of the sea). It means that the pattern of water dynamics in different areas of the North Caspian Sea was notably changed and the residence time of water in 1990 increased in comparison with 1982 and 1984. It specifically refers to the area III (see Table 2), where water exchange with the Middle depression was slowed down. From calculations based on tritium data and the model of complete mixing residence time of water of area I (western part) in the period of 1980-1984 is equal to 2 yr and of the area III (eastern part) is 5 yr. It follows also from the Table 2 that the role of river water in formation of the area III water masses was increased and the value of  $Q_p/Q_{mic}$  in 1990 was equal to 1.8 in comparison with 1.0 in 80th.

### 3. VERTICAL SEA WATER EXCHANGE.

The Middle and South Caspian Sea depressions contain major portion of the sea water. Proportions of its volume for northern, middle and southern parts are like 1:70:130. It was found that during the period of the sea level rise mean air temperature was rised but the sea surface temperature was slightly dropped. In order to understand natural mechanism of water temperature variation and the role of vertical mixing effect in this process tritium studies in the middle and south depressions were undertaken. Cruises for water sampling were organized in 1983 and 1991 along five latitudinal and in 1994 along longitudinal sections (Figure 4).

Since 1953 tritium contents in river and precipitation over the sea were reconstructed using experimental and extrapolation data (3). Maximum values of 530 and 350 T.U. for precipitation and river water were determined for 1983 from 1963-1964 fallout after decay. The concentration of tritium in surface sea water in 1983 and 1991 were dropped up to 49 and 34 T.U. accordingly and its content in river water and precipitation did not exceed 30 T.U. Because of present tritium concentration in precipitation is close to that in surface water, the effect of isotopic molecular exchange is neglected in interpretation of the measurements.

The found tritium distribution in the recharged water enables us to evaluate the process of river and sea water mixing and of water exchange characteristics of the sea as a whole.

Maximum peaks of tritium concentration in 1983 were fixed on the depth of 200 m in the middle depression ( 174 T.U.) and of 600 m in the south depression (56 T.U.). These data indicate on the presence of bomb tritium of 60th in deep waters and give the idea of scale of time in water exchange. Maximum concentrations in 1991 were found on the depth of 70-200 m in both depressions. And the measurements of 1994 samples show practically uniformity in tritium distribution in all the sections (Figure 5). The authors interpretation of the experimental data is as follows.

Because of increase since 1978 of the river runoff which is cold water from the east-european catchment area, the replenishment and displacement of bottom water masses of the middle and south depressions were intensified. At the same time mixing process of the cold bottom and warm surface waters was accelerated. The observed bomb tritium rise in the deep depressions was traced this phenomena. Using tritium balance approach, it was found for both the middle and south depressions and for the sea as a whole, that the value of mean velocity of the deep water rise in 1983-1991 is equal to 13 m/yr. This figure is in accordance with calculations based on hydrological data and on the movement in time tritium concentration peak along the section of deep water. These two approaches gave 10 and 15 m/yr accordingly.

The data of 1994 sampling campaign proves the above ideas. After 1991 the exchange process reached the stage of complete vertical mixing of water. It is assumed that the cycle started in 1974. Mean value of tritium concentration of all the analysis is determined by  $33.7 \pm 10$  T.U. Tritium content in runoff water and precipitation in 1991-1994 is accounted by 34-39 T.U. (mean value is 36.5 T.U.) and in the surface sea water of 0-30 m depth is by 34.3 T.U. In this situation it is not expected notable tritium gradient between deep and surface waters. It means that intensity of vertical water

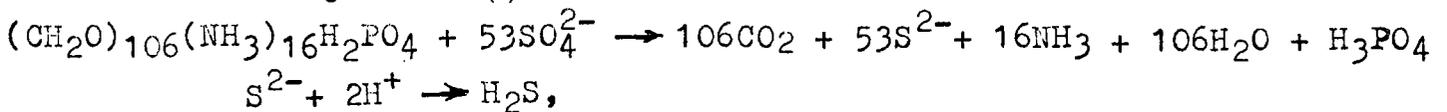
exchange is expected to be decreased and the temperature of the surface layer should start to rise. As a consequence of this process the sea level rise should go to stabilization and later on to decrease. The authors' understanding of the mechanism of permanent short-periodic variation is based on the water exchange effect within the basin in general and on the cold bottom and warm surface water mixing process in particular.

#### 4. PRELIMINARY RESULTS OF BOTTOM SEDIMENT STUDY

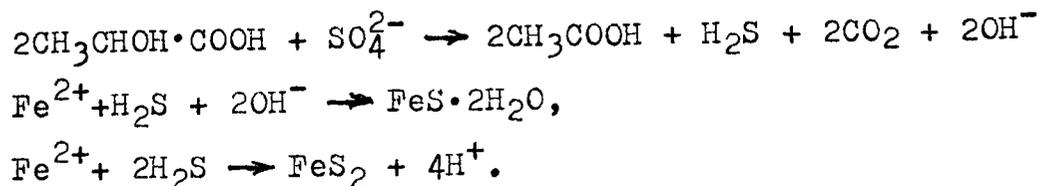
During 1994 cruise a number of bottom sediment cores from the depth of 500 to 800 m were collected (Figure 4). The cruise was organized in framework of French-Russian research program. The core length reached of 1 to 10 m. The mineralogical, chemical and isotope analysis of the core sediments are still in operation. But some significant results is possible to report now.

The regular quasi-periodic alteration of hydrotroilite ( $\text{FeS} \cdot n\text{H}_2\text{O}$ ) and silt sediment layers were discovered in the deep parts of depressions of the Middle and South Caspian Sea. The black colour hydrotroilite layers of 1-5 mm thick are interchanged with gray consolidated silt sediments of 3-15 mm thickness (Figure 6). Marine sedimentologists and chemists describe their findings of the troilite in form of layers, concretions and grains in Caspian, Black, Barents and other seas explaining its formation by sulfate reducing action of bacterias in anaerobic conditions (4,5). But there is no explanation of the observed regularities in periodic accumulation of the troilite layers which have spacious horizontal extention. It is well known that variation in mineralogy and chemistry along sediment section is clear evidence of changes in the governing processes during or after sedimentation. The main source of organic component in the Caspian Sea sediments is phytoplanktonic debris. Growth of planktonic population is in close correlation with water circulation intensity and with the sea level variation in particular.

The bacterial sulfate reducing process starts in bottom anaerobic conditions after reserve of the dissolved oxygen drops to lower of 0.11 ml/l and denitrification of  $\text{NO}_3$  and  $\text{NO}_2$  is exhausted. The reduction of sulfates is accompanied by production of hydrogen sulfate, hydrotroilite and pyrite in reactions with organic matter (5):



or with organic acids:



The observed discontinuation in hydrotroilite accumulation meas that the sulfate reducing process was periodically stoped or damped. Analyses of troilite distribution in the modern core sediments gives the following information. The size of troilite creatures in the form of microseeds to submillimeter layers depends on amount of seasonal sedimentation of organic matter. Farther process of sediment consolidation by displacement of pore water brings together seasonal creatures into troilite layers of different thickness or dispersed seeds and concretions depending on proportion between the troilite and calsiium carbonate, which is the main component of the sediments. So, the most probable causes of the observed periodicity in the troilite layer formation could be variation in the amount of seasonal sedimentation of organic matter or/and changes in dissolved oxygen inflow to the bottom sediments. In both cases troilite accumulation process is developed in close relation with intensity of water circulation and sea level variation.

The presented in Figure 6 fragment of sediment core from the Middle Caspian Sea depression (coring point SR-9409-GS-19-VIII) shows a picture of the described character of troilite layer distribution and the variation of  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  in the sediment carbonates. Two periods of sea level rise

accompanied by cooling of water up to 4°C within the intervals of 0-15 cm and 32-50 cm and one period of its decrease and warming of water up to 3°C relative to modern value are observed here. And also short-periodic variation in oxygen and carbon isotope content with more detailed changes in the troilite sedimentation in the basin are seen.

Farther analyses of the core sediments which is in progress will give more experimental data for extensive interpretation.

## 5. CONCLUSION

First steps of application of isotope techniques in the study of environmental changes in the Caspian Sea basin have been done.

It is planned to extend the work in all directions including co-operation with the IAEA which has just established its Caspian Sea regional project for riparing countries.

## REFERENCES

1. Baydin, S.S., Kosarev, A.N. (Eds), *The Caspian Sea: Hydrology and Hydrogeochemistry*, Nauka, Moscow (1986).
2. Brezgunov, V.S., Study of water exchange in sea-river water mixing zone using the isotopic composition-salinity diagram, *Nuclear Geophysics* 4 (1990) 71.
3. Vlasova, L.S., Romanov, V.V., Anosova, N.B., and Perminov, S.M., Tritium study of Caspian Sea water dynamics, *Water Resources* 3 (1989) 176.
4. Maev, E.G., Bagirov, V.I., Iron sulfides in bottom sediments of Caspian Sea, In: *Comprehensive Study of Caspian Sea* (Leontiev, O.K., and Maev, E.G., eds), Moscow Univ., Moscow (1970) 90.
5. Horne, R.A., *Marine Chemistry*, Wiley, New York (1969).

## CAPTIONS:

Fig 1. Geomorphology of Caspian Sea bottom: (1) Bathymetry and (2) River palaeobeds (1).

Fig 2. Variation of water level (a), runoff (b), precipitation (c) and temperature (d) of the Caspian Sea during the last 100 years.

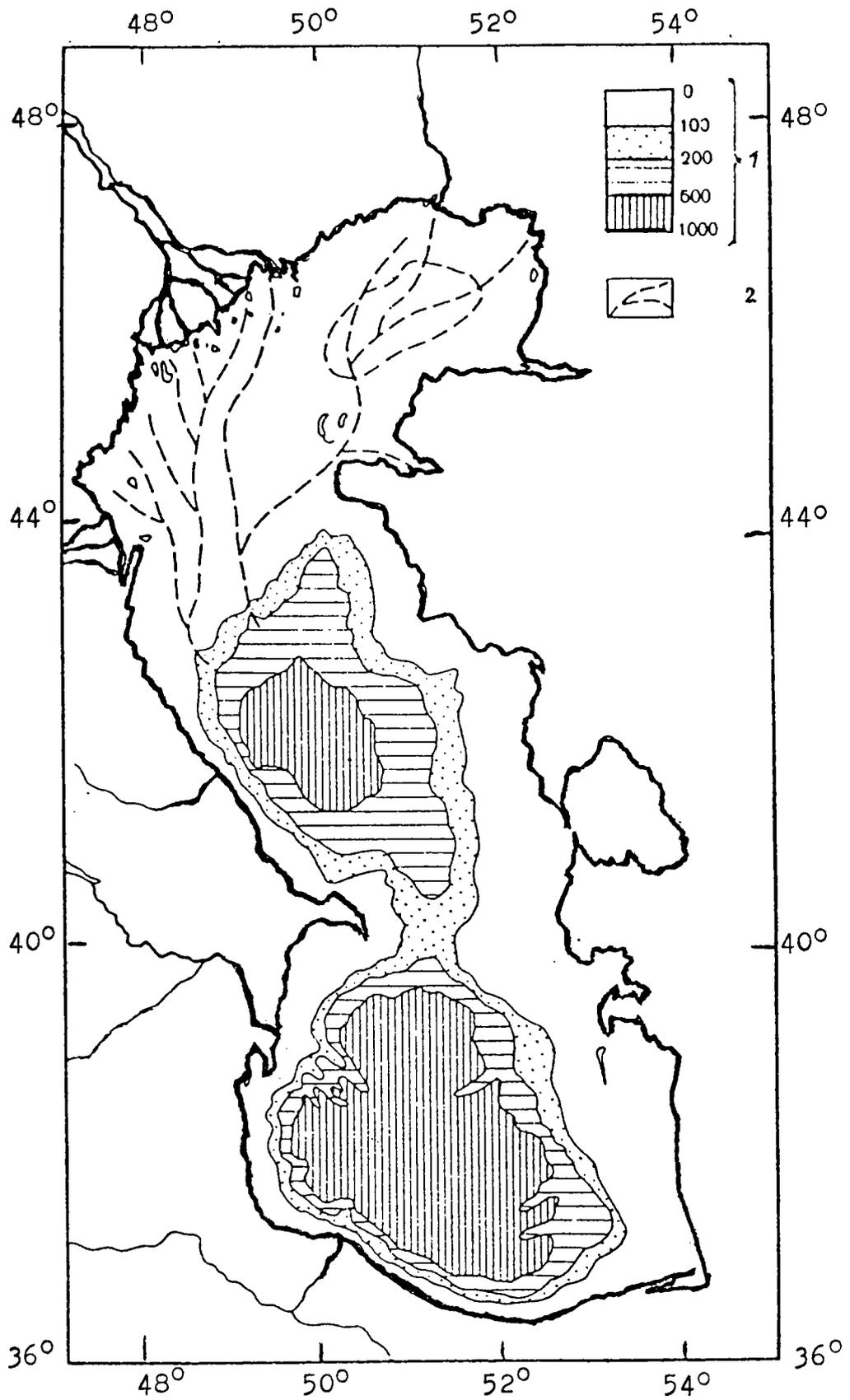
Fig 3. Diagram of  $\delta^{18}\text{O}$  - S relationship for the water samples collected in North Caspian Sea in 1982.

Fig 4. Points of water and bottom sediment sampling during 1983-1994 cruises.

Fig 5. Profiles of mean tritium value variation for basin area of (a) all the Caspian Sea, (b) middle and (c) south parts.

Fig 6. Fragment of sediment core SR-9409-GS-19-VIII section with troilite layers (black) and oxygen and carbon isotope variation profiles.

Figure 1. Ferronsky et al.



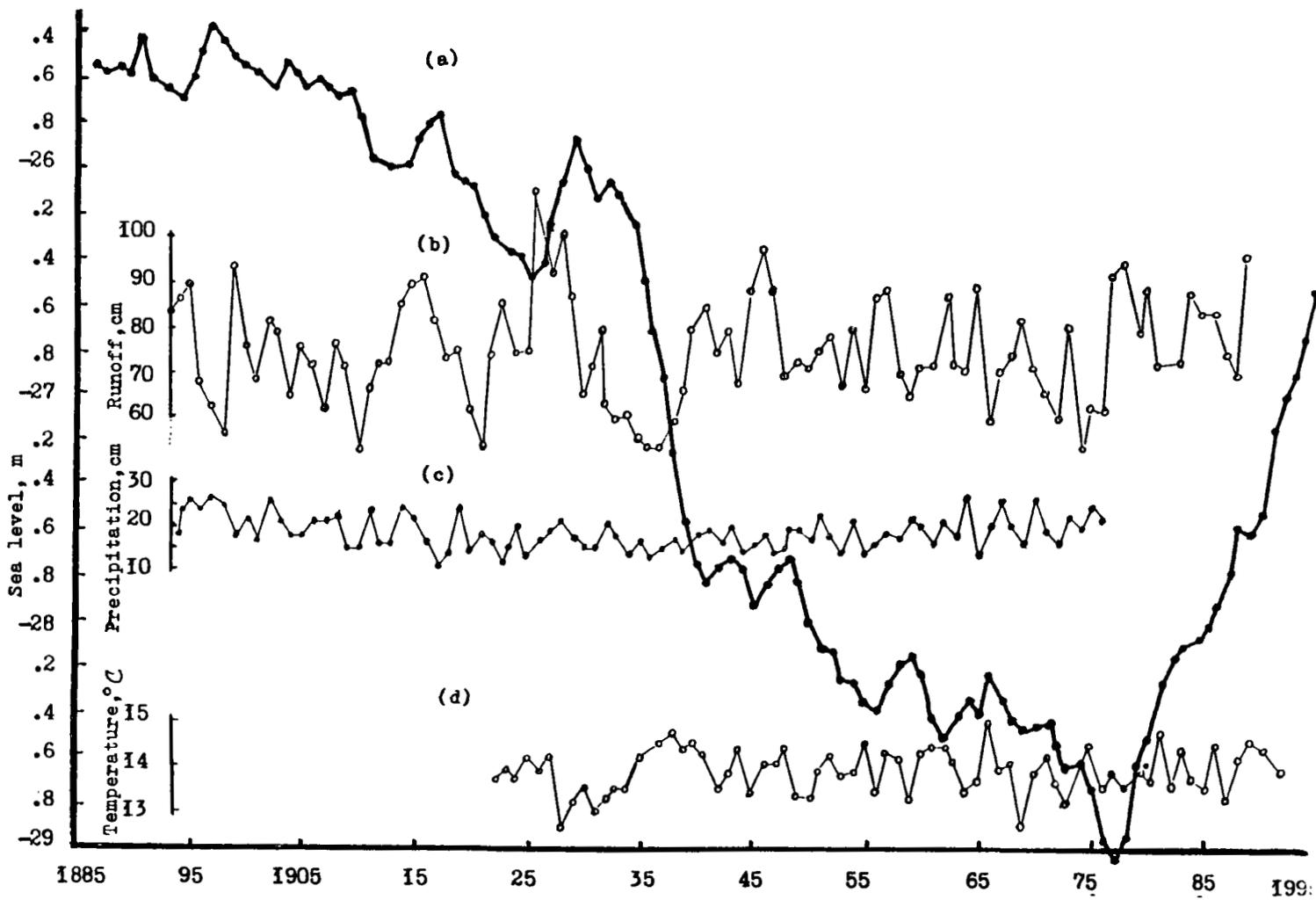


Figure 2.  
Ferronsky et al.

Figure 3.  
Ferronsky et al.

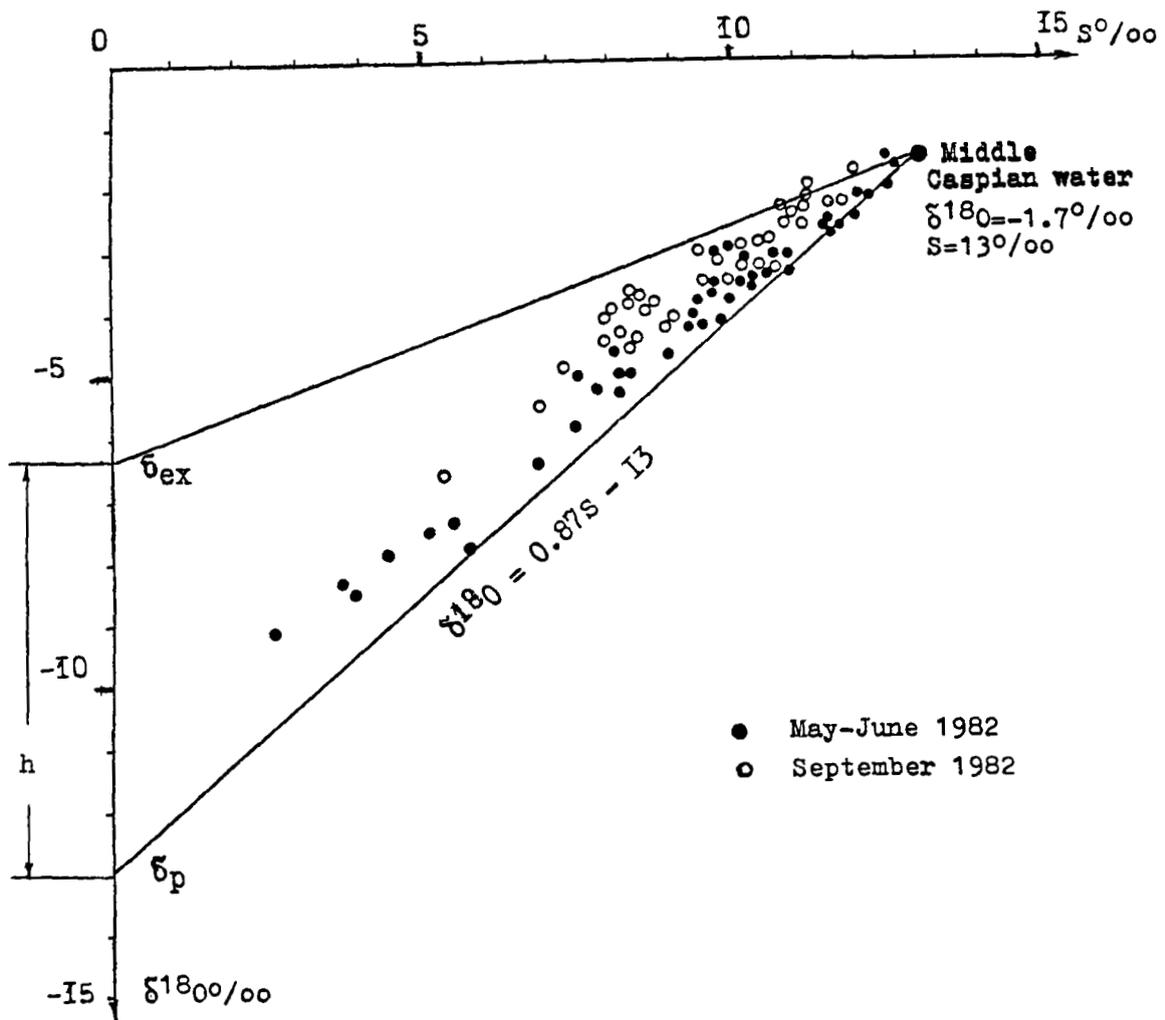


Figure 4.  
Ferronsky et al.

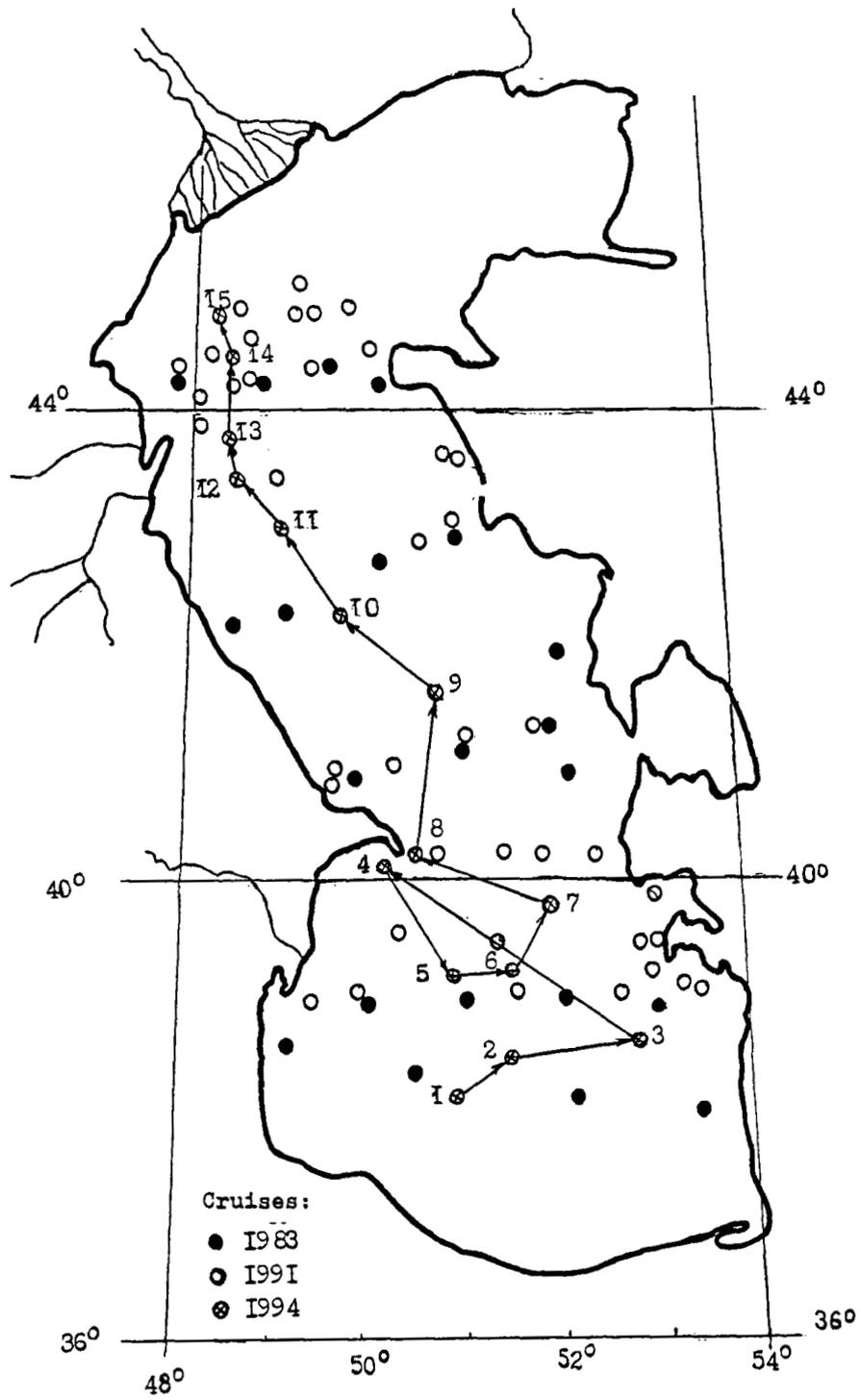


Figure 5.  
Ferronsky et al.

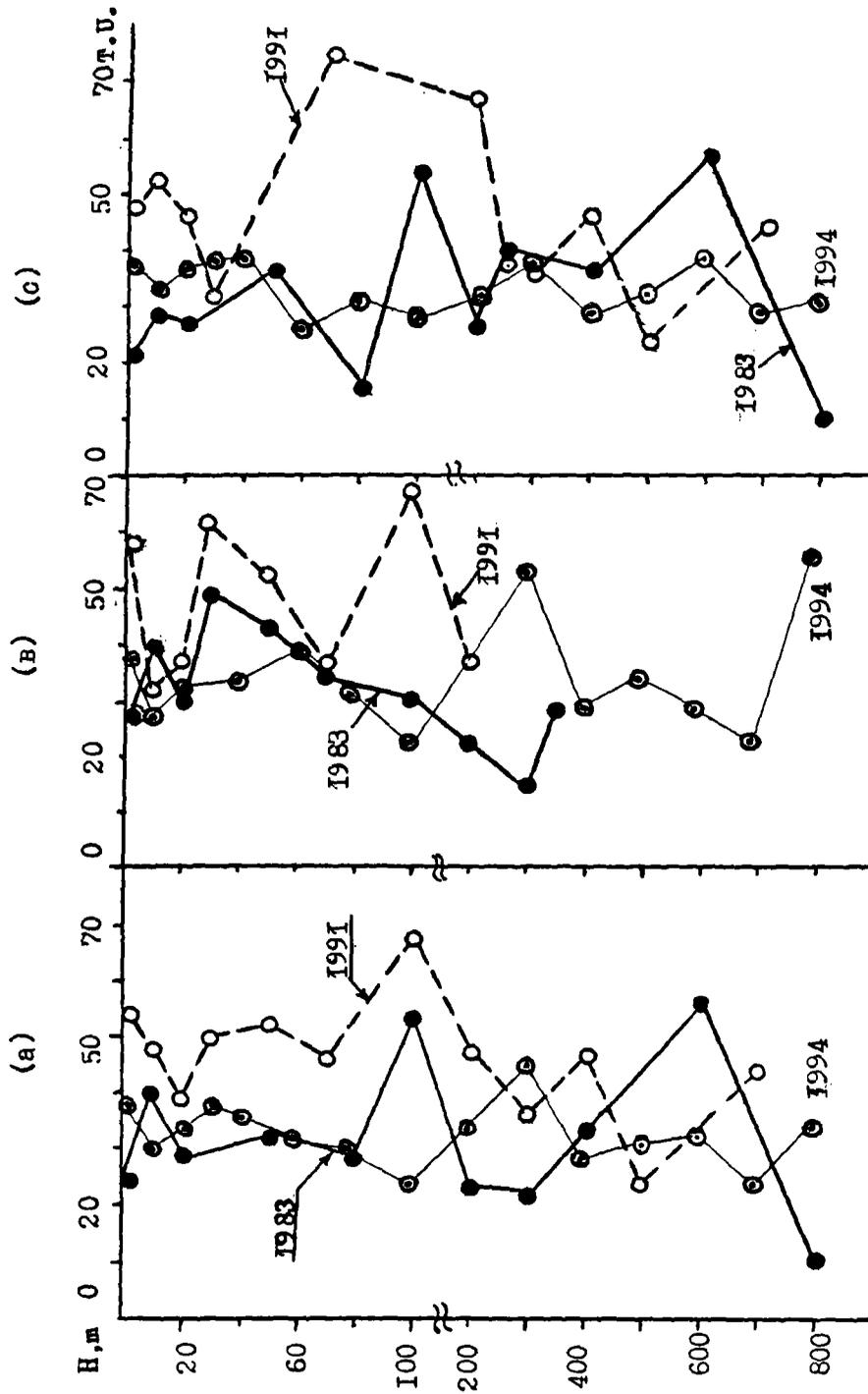
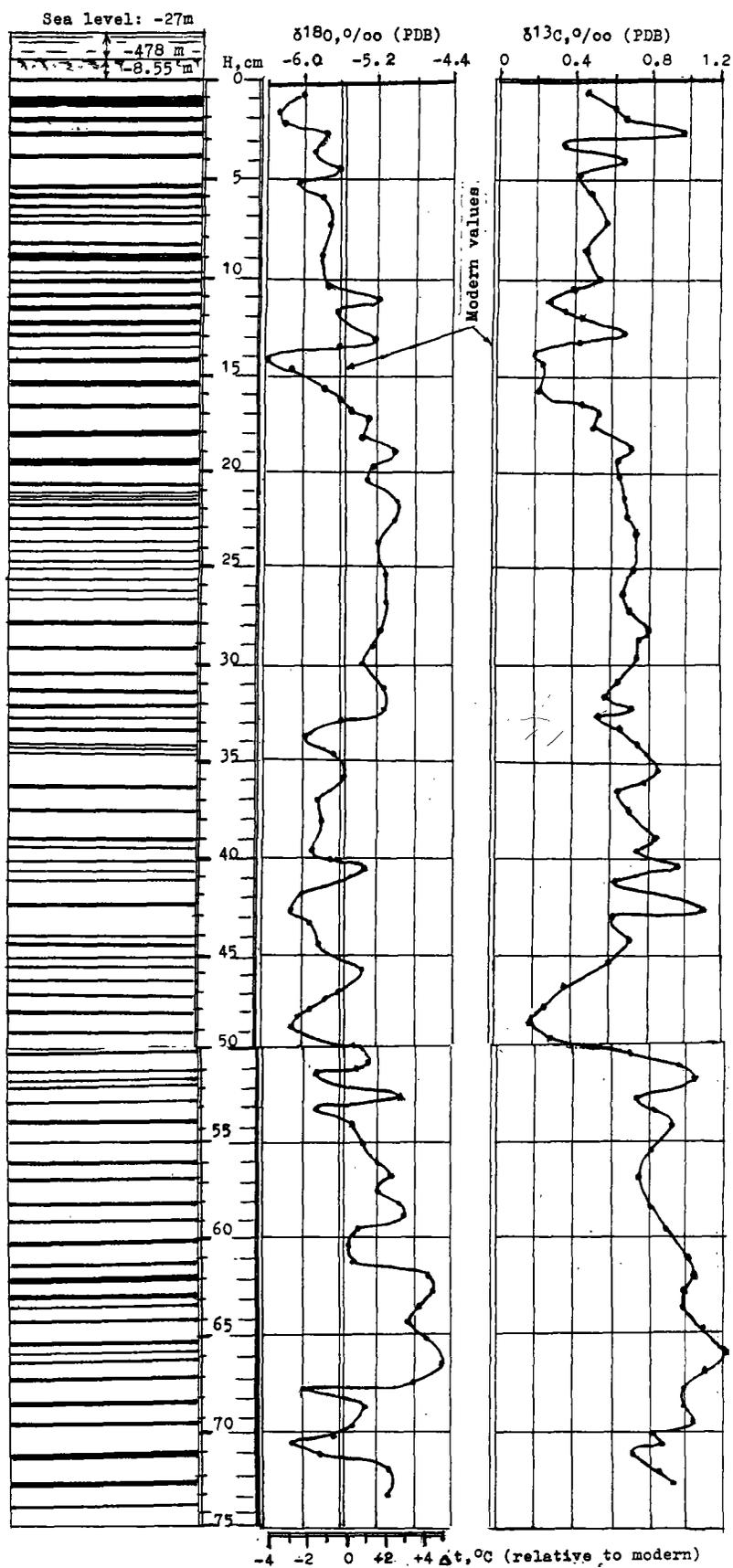


Figure 6.  
Ferronsky et al.



**BASIC APPROACHES TO THE PROBLEMS  
LINKED TO THE RISE IN THE LEVEL OF THE CASPIAN SEA**

K. Salykov  
Head of the Group of Experts of the National Council  
of the Republic of Kazakhstan,  
Director of the Division on Problems of the Aral and Caspian Seas,  
Committee on Water Resources

Ladies and Gentlemen, Friends,

We are pleased that this workshop is being held at a very opportune moment, and we convey our thanks to the organizers, IAEA and UNESCO.

In recent years, the Republic of Kazakhstan has been actively addressing the problems of the Caspian Sea. As you know, the greatest area of shoreline expansion is occurring in our territory, which has the flattest coast.

Forecasts of the level of the Caspian Sea based on materials at our disposal vary considerably. At present, there is a lack of reliable scientific methods for long-range forecasts of the climatic conditions and hydrologic regime of the Caspian Sea. Our projections are examined in an overview document as a basis for determining the various possible scenarios regarding changes in the ecological and socio-economic systems.

The forecasts of our specialists and scientists are contained in a feasibility report entitled "*Obsespecenie ustojcivoj ziznedejatel nosti naselenia i zascity narodnohozjajstvennyx objektov i naselönnyx punktov v probreznoj zone Kaspijskogo morä v predelax Respubliki Kazaxstan*" (Ensuring sustainable economic activity for the inhabitants and protection of national economic facilities and inhabited localities along the Caspian shore within the territory of the Republic of Kazakhstan, in Russian only), drafted by our committee and approved by the Council of Ministers of the Republic of Kazakhstan as a scientific and technical bases for decision-making to ensure sustainable economic activity and the protection of inhabited localities from flooding and submersion in the Kazakh portion of the Caspian.

The scientists of Kazakhstan, the Russian Federation and other Caspian states are of the view that the current rise in the level of the Caspian is basically the result of a significant increase in precipitation and surface runoff in the Caspian basin, a decrease in evaporation rates arising from regional climatic changes, and surface pollution.

Kazakh scientists have recently suggested that some of the basic causes of the rise in the level of the sea lie in the seismo-tectonic, morphodynamic and hydrogeologic processes occurring in the sub-marine deposits. As a result, the level of the sea may reach the -25 m contour line around the years 2025-2030.

In addition to changes in the level of the Caspian Sea, there are also wing-surge phenomena. The average duration of wind-surges is two days; their annual frequency has increased, and wave heights occasionally attain 3 m.

As a result of a rise in the level of the sea of over 2 m in the past 17 years in the Kazakh portion of the coast alone, some 1.2 million ha of land has been flooded. Built-up and inhabited areas and areas occupied by industrial facilities account for 4 to 6 per cent of the total area of flooding; 0.57 million ha of agricultural land, or 25 per cent of the total, has been flooded. Some 300,000 people inhabit the areas affected by flooding and wing-surges. The area affected by rising sea levels contains large-scale industrial complexes comprising the majority of the region's industrial enterprises and oil facilities.

The rising sea levels have severely affected agricultural production in the region. The total area of farmland in the zone of flooding and submersion between -27 m and -25 m is 775,000 ha. The area affected by rising sea levels includes all 10 fishing facilities. A whole range of water facilities have had

to be closed down: some 1,300 km of irrigation channels, regular and estuary irrigations systems (38,500 ha), and over 1,500 hydraulic plants and pumping stations. The area affected by flooding and wind surges contains over 700 km of metalled roads, a total of 290 km of railway lines, the airports of Atyrau and various regional centres, and the sea ports of Atyrau and Bautino. Some 890 km of pipeline is under the threat of flooding or submersion, and over 900 km of electric power lines are located in the area affected by rising sea levels.

If no protective measures are taken, the total damage to the economy may approach the \$US 1 billion mark.

This threat means that there is a need to seek ways of protecting our national economic assets and completely preventing or, at least, minimizing losses. Scientists and specialists have all opted for civil engineering protection of installations and inhabited localities. The plans they have adopted for the protection of the coastal areas are based on a number of fundamental considerations. Taking into account the complexity of the environmental situation, and taking as our guide the principle of "reasonably sufficient" protection, we are primarily seeking ways to ensure maximum prevention of damage at the lowest possible cost of protection.

Secondly, protection of the population and valuable economic facilities requires the protective works to be as reliable and durable as possible.

Thirdly, practical action has taken the form of the phased implementation of a set of protective measures.

An integrated approach to protective measures should ensure not only protection from the sea but also the prevention of marine pollutions arising from the building of protective structures, together with possible measures to regulate the level of the sea.

The nature of the impact of the sea on facilities made it advisable to divide the protective measures into two types: protection from wind surges only and protection from the combined effect of the background sea level and wind surges.

The type of protection is determined by the economic value of the facilities along the coast and the extent to which their operation is linked to a particular site: either active protection provided by civil engineering works, or passive protection through the relocation of plant and the resettlement of inhabitants.

The particular physical and economic conditions and features of the assets requiring protection make it necessary to implement various types of protection, from the complete enclosure of the most developed parts of the coastal area to local protection of individual facilities.

The first phase (up to the year 2010) will provide protection to all inhabited localities and economic facilities located between the -27 m and -26 m contour lines from the effect of the background level and wind surges, and to localities and facilities in the zone located between the -26 m and -25 m contour lines from the effect of wind surges only. During this phase structures may be enlarged, if necessary, and facilities located at higher elevations will be protected.

The decision whether to provide active protection or to relocate facilities has been taken on the basis of comparative studies of the technical and economic implications of such measures. In a number of cases, where economic assessments have proved difficult or had low priority, the choice of type of protection has been made by taking into account national, social, environmental and other factors.

Drawing on local and foreign expertise in protective structures, we have selected as the principle means for the protection of facilities and inhabited localities earth dykes built with local soil, with reinforcement of the water slope by a stone embarkment. Preliminary hydrologic calculations taking into account the characteristics of wave phenomena in the Caspian have shown that this type of protective dyke gives the best guarantee of reliable and durable protection.

On the basis of our feasibility report, work is currently under way for the protection of coastal areas, using funds from the state budget; significant portions of the protective works are being financed from local budgets and the funds of enterprises. A number of local protection projects have already been designed or are being designed. These are exceptional measures, which are being financed chiefly from our emergency fund, but they are not adequate to meet the rate of sea level rise; they nevertheless account for 10 per cent of the total volume required. We know how to protect ourselves, but we do not have the necessary material or technical resources to do so. Hence, the research and project development necessary for protection is beyond our capacity; we need the help of the world community.

In this connection, we feel that an intergovernmental Caspian scientific co-ordination council to be composed of scientists and specialists from the Caspian states and other countries should be established. At the same time, we feel that it is necessary, first of all, to create an intergovernmental body with the task of executing the necessary recommendations and proposals of the above-mentioned council. We now have a basis for scientific regulation of the level of the sea. A feasibility report and a feasibility study have been made in Kazakhstan and the Russian Federation respectively. As we now know, similar work is also under way in Azerbaijan, Iran and Turkmenistan.

There is a particular need to pool efforts in order to solve the problem of regulating the level of the Caspian Sea. There are quite a number of proposals in this respect: some authors propose that excess water be transferred from the Caspian to the Aral Sea. These issues should be resolved through the joint efforts of the Caspian states. In this connection, it should be borne in mind that the Russian Federation's feasibility study is aimed at reducing the rate of sea level rise by flooding coastal depressions located in Kazakh territory. In our view, a decision along such lines should be taken only after further careful examination of the consequences of such measures, since some of the depressions it is proposed to flood have in recent years been the scene of sizeable engineering works - corridor have been built, and in many cases these provide the only form of communication for civil engineering purposes. Natural gas and uranium deposits have been discovered and are now being exploited, and new farmland has been established. Therefore, these issues require further joint examination.

Kazakh, Uzbek and Russian specialists and scientists have proposed a number of projects for the transfer of water from the Caspian to the Aral Sea. There is a project for the construction of a Volga-Ural canal for the irrigation of Russian and Kazakh arable land in the interfluvium between the Volga and the Ural. All these and other measures require general agreement, which it will not be possible to achieve without the establishment of the above-mentioned intergovernmental and scientific bodies. Furthermore, the experts of some Caspian states consider the adoption of a convention on the legal status of the Caspian Sea to be a matter of prime importance. Given the new geopolitical situation, we feel that such an approach is the correct one.

In conclusion, I should like to call that this workshop has been examining issues relating to the rise in the level of the Caspian Sea and the research needed on that subject. It should be noted that no single Caspian state will be able to solve this problem alone. There is a need to pool the efforts of, first and foremost, the Caspian states, and of the world community as a whole.

On the basis of the proposals of the Government of Kazakhstan, a number of international organizations are now taking an interest in this problem. In our view, it is necessary to designate an international lead organization, whether IAEA or the World Bank, as rapidly as possible.

Secondly, I should like to suggest that international organizations take into account the work taken under by the Caspian states and, in carrying out further research that they make extensive use of the services of scientists and specialists from those countries.

## THE DETERMINATION OF BACKGROUND VALUE LEVEL OF CASPIAN SEA FOR PERSPECTIVE AND ITS LEVEL RISING BY EFFECT OF WIND

A.A. Skakov, V.V. Golubtsov, S.P. Shivareva  
Kazakh Scientific - Research Hydrometeorological Institute (KazNIGMI)  
Almaty, Republic of Kazakhstan

### 1. INTRODUCTION

The Caspian Sea is the largest basin without outflow on the globe. Its water surface covers 350,000 sq. km, and the drainage area is about 3,100,000 sq. km. The river Volga, Kura, Ural, Terek, Sulak, Samur and a number of smaller tributaries run into the sea, the waters of the latter reach the sea only in wet years. The Caspian Sea is characterized by quasi-periodic (cyclic) water level fluctuations. The amplitude of these fluctuations for the last five centuries reached 7 m. The design of hydraulic structure, as well as industrial and economic objects in the coastal zone proceeds from the calculated parameters of Caspian Sea level. It is therefore necessary to provide the designing and constructed organizations with sufficiently substantiated data on high sea levels of rare recurrence.

### 2. THE CHARACTERISTICS OF SEA LEVEL FOR CONSTRUCTIVE PROJECTING NEEDS

The rise of the Caspian Sea level has been going on for 17 years (1978-1994). In the course of that period the sea level rose for 2.4 m and by early 1995 reached the mark -26,7 m. The average sea level rise intensity in those years was about 14 cm per year. This sea level rise is no extraordinary phenomenon. Similar sea level rises in height and average intensity was observed in the 18th - early 19th - centuries.

To determine the levels of various frequency used were the reconstructed and observed values of the element of the water balance for 1956-1993. The problem of calculating the prospective background sea levels was solved through their modeling by means of the water balance equation with values: the runoff into Kara-Bogas-Col. Bay under present-day conditions and the "visible" evaporation (evaporation's minus precipitation's). The calculations made in the Kazakh Scientific-Research Hydrometeorological Institute show that under present-day climatic conditions with the water consumption in the Caspian basin reaching 40-45 cu.km. per year the sea levels of 1% frequency (repeated once in a hundred years) have the mark of about minus 26 m. For the needs of construction projects and works in the coastal area recommended may be as the ultimate mark (at least till the year 2020) that of 0,1% frequency (return once in a thousand years) equal to minus 25 m. abs. Under natural conditions and with no water consumption in the Caspian Sea basin this value corresponds to the sea level mark of minus 2,2 m, which is the highest of the recent 2000-2500 years.

When planning any works in the coastal zone it is necessary to have at one's disposal the data on high level of infrequent occurrence for the nearest and more distant future. Calculations show that with the confidence coefficient of 96% (2% frequency) the sea levels in 1995, 2000 and 2010 will not exceed the marks respectively of minus 26,5 m, minus 26,3 m and minus 26,2 m. The investigation results indicate a very low probability of further continuous sea level rise in the nearest years and a transition for a certain period to stabilization within the range of reached marks with a slight trend towards reduction. After the stabilization period and some fall of the level a new period may begin with the level rising above the marks of infrequent occurrence.

During the raising of the water level by effect of wind on the Caspian Sea coast the levels rise above the background value. These rises of 2% frequency on the coast of the Republic of Kazakhstan vary from 0.7 to 2.6 m according to the geomorphologic conditions of the coast and the wind regime. To eliminate the sea water effect upon structures and other objects the designed levels should be marked taking into consideration that the background levels will be above norm during raising of the water level by the effect of wind.

CHANGING THE CASPIAN SEA'S LEVEL DURING 1556-1992

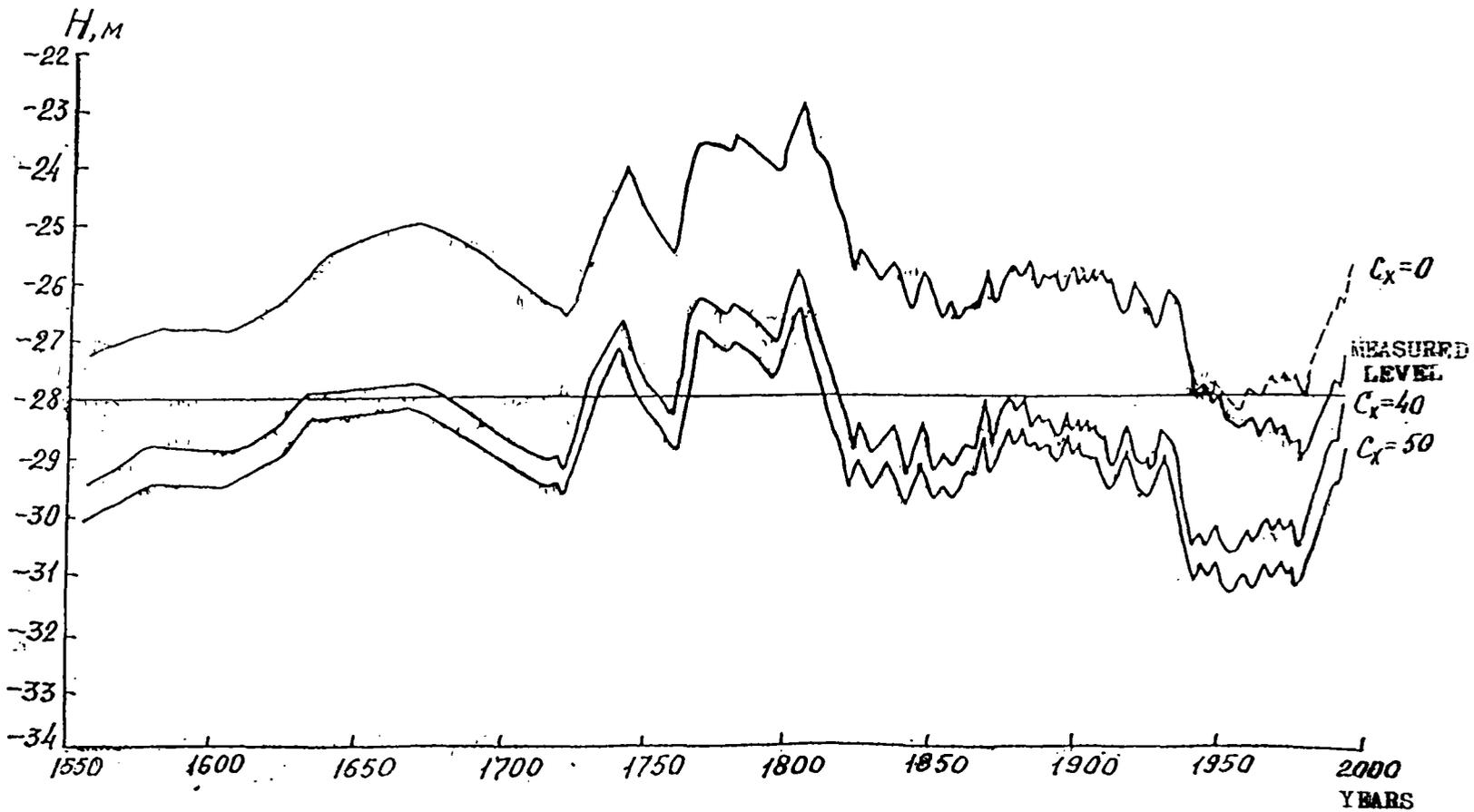


Fig. 1. HISTORICAL DATA, OBSERVATIONS (VALUES OF MEASURED LEVEL) AND RESULTS OF CALCULATION WITH THE WATER USING  $C_x$  EQUAL TO 0, 40, 50 km<sup>3</sup>/year

Fig. 2. DIVIDING THE CASPIAN SEA'S COAST INTO DISTRICTS  
BY MAXIMUM HEIGHT OF ONSET WITHIN THE REPUBLIC OF KAZAKHSTAN

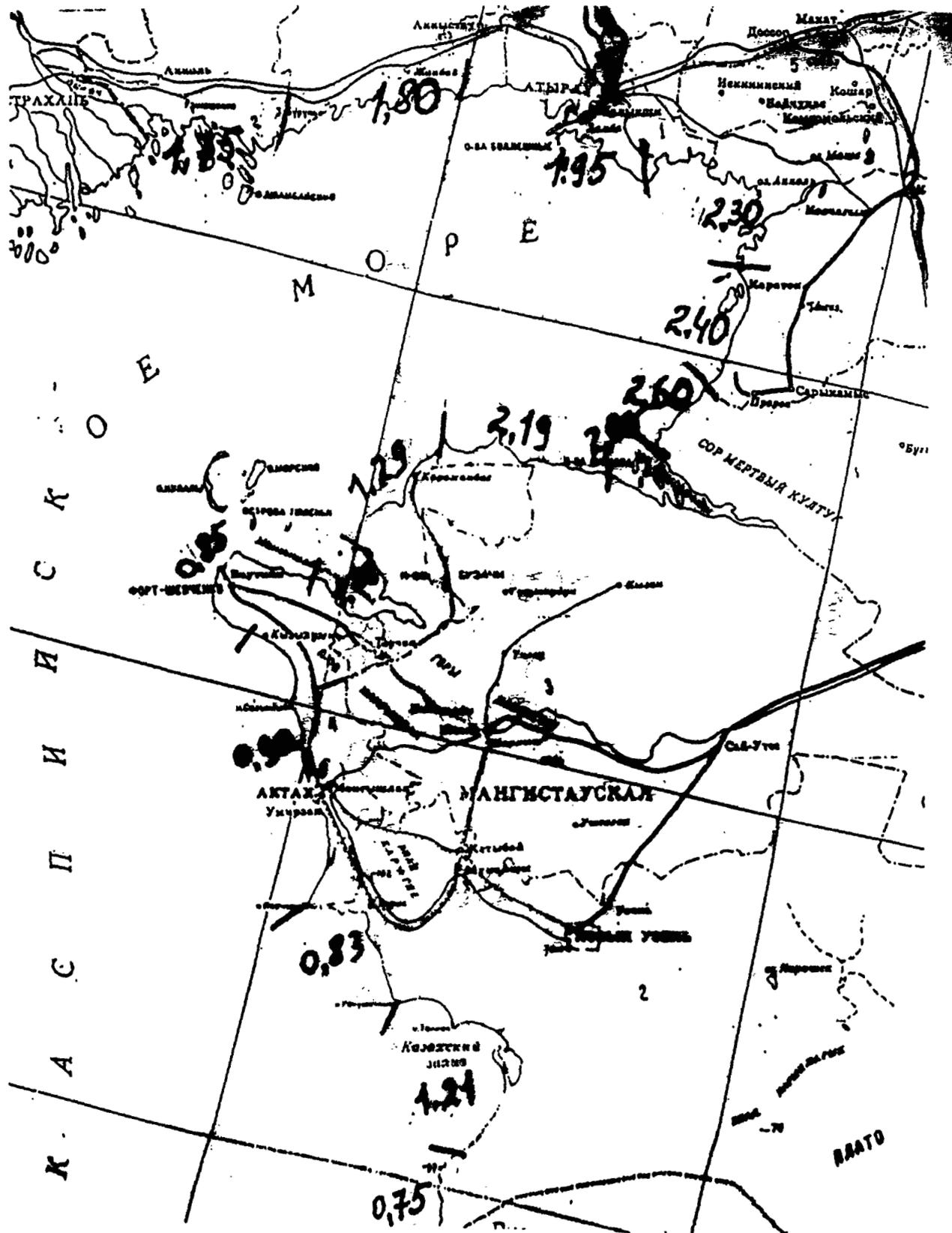
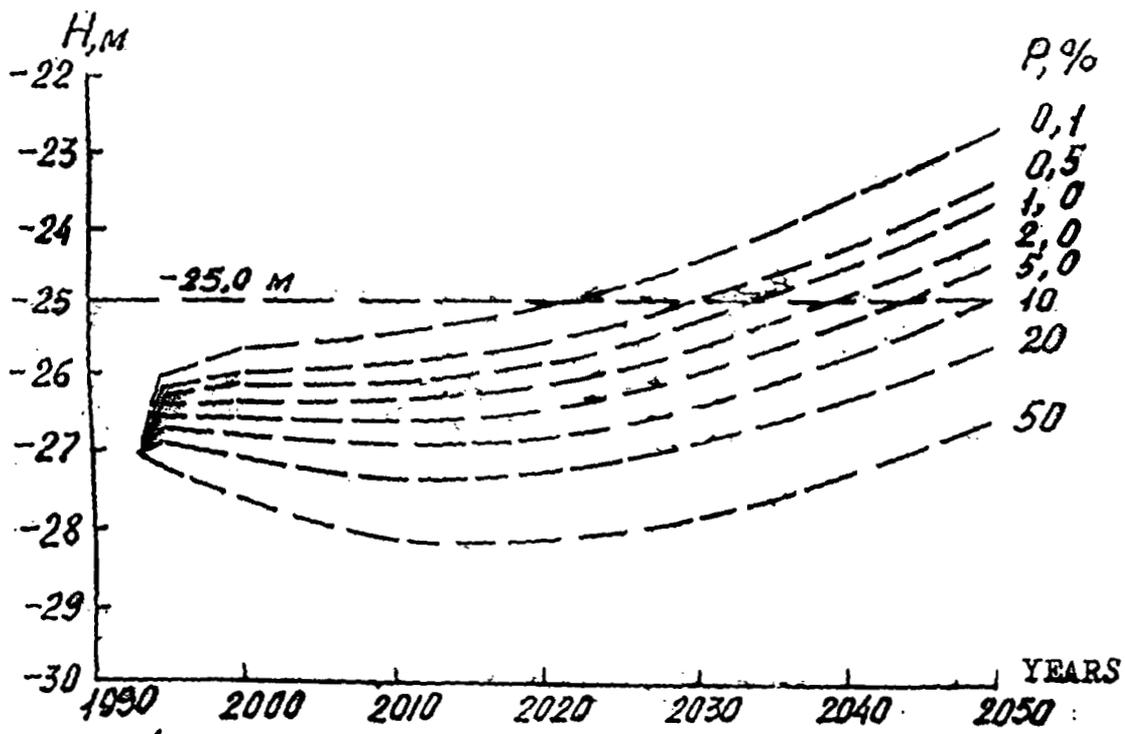


Fig. 3. ORDINATES OF CONDITIONAL CURVES  
OF THE CASPIAN SEA'S LEVEL PROBABILITY, COUNTED TILL 2050  
TAKING INTO ACCOUNT POSSIBLE ANTHROPOGENIC CLIMATE CHANGING



P - PROBABILITY, %

## LONG-STANDING FLUCTUATION OF THE LEVEL AND FLOODING OF THE CASPIAN SEA AT THE CONTEMPORARY STAGE

M.R. Mansimov  
Vice-Chairman of the State Committee on Hydrometeorology of  
the Azerbaijan Republic

The problem of change of the level of the Caspian sea has always worried and worries the people living on their coasts. The situation of people settlements, social-economic and agricultural objects situated on the coastal zone of the Caspian sea depends directly on fluctuations of the sea level.

During last 2,5 thousand years the amplitude of the level fluctuation reached 15 m. The transgression and regression of the sea with interval from -34 to -21 m/abs/ were revealed during this period. The last 200 years the change of the Caspian sea level reached 4,5 m: it reached a climax in 1804-1805 and a minimum in 1977.

The level of the sea fell continuously from 1930 to 1977. This fall made up more than 3 m. Beginning from 1978 to present time the level of the Caspian sea rises. The average level reached -26,60 m.abs. in 1994. It is above on 2,4 m. of the level in 1977 (Fig.1) .

According to the facts of many investigators the principal reason of long standing fluctuations of the level of the Caspian sea is the change of the Climate forming factors, having influence on the formation of elements of water balance of the basin /on the river gutter, precipitations, evaporation etc./ and leading to changeable of correlation between its separate elements. It's determine of cyclic changes of the sea water volume and corresponding its cyclic fluctuations of the sea level difference long: from 2-3 summers to centuries. These fluctuations have irregular character, therefore difficult predict.

Climatic anomalies led to great changes of the sea level position. All northern hemisphere was enveloped by large anomaly at the beginning of the current century and reached maximum in 30 years, led to the most sharp lowering of the sea level for short terms (1930-1941) on 1,8 m. In 1970 in the sea basin were the same conditions. The climatic changes led to the sea level rise, that show it the last sharp rise, which began from 1978 and continue to the present time.

The actual sea level rise made up more than 2,4 m., is not an abnormal phenomenon. Similar changes were observed at the end of the past century as well as now; from 1862 to 1869 and from 1873 to 1878 the sea level rise was accordingly about 1,0 and 0,6 m., and from 1914 to 1917 and from 1926 to 1929 -0,5-0,6 m. The sea level rises taking place since 1978 is the longest of all periods of hydrometeorological observations since 1830.

In opinion of some scientists, cause of the Caspian level fluctuating in the present geological century are technological processes. However, many researches show that tectonic movements in Caspian level change have only minor meaning and modern movements are not exceed few millimetres a year, therefore its contribution to level yearly change too little.

Analise of the zero vertical transferences all basic level posts of the Caspian sea, shows about different direction of these movements in the different parts of the sea and different speed of transference for the long-term. (Fig.2)

One of important cause long-term changes of the Caspian level is influence of economic activity especially on the river runoff to sea.

According to the data presented by State Hydrological Institute of the Russia, volume of water-use at the Caspian basin consist 40-50 km<sup>3</sup> a year. Consequently, at the natural conditions, level in the present time could be on 1,0-1,5 m higher than actuals.

This way, year-to-year fluctuation of the Caspian sea level in the present time determining by combination of the climatic and antropogen factors, climatic factors are prevail.

Climatic changes pronounced in the element changes of the water sea balance (table 1).

TABLE 1. AVERAGE LONG-TERMS MEANING OF THE WATER BALANCE COMPONENT OF THE CASPIAN SEA

Periods	Runoff to sea km <sup>3</sup>	Precipitation km <sup>3</sup>	Evaporation km <sup>3</sup>	Runoff to Kara-Bogaz-Gol	Level change sm/a year
1900-1929	332	70	389	21,8	-1,4
1930-1941	269	73	395	12,4	-15,7
1942-1969	285	74	356	10,6	-0,9
1970-1977	240	88	375	7,1	-13,6
1978-1993	314	90	347	4,3	15,0

Note: Subsurface flow to the sea accepted by constant 4,0 km<sup>3</sup> a year, runoff to Kara-Bogaz-Gol 1980-1984 was absented, from 1985-1992 bay was brought -1,6 km<sup>3</sup>, in 1992-1995 after the open of dam 15,3 km<sup>3</sup> a year.

Modern level rise of the Caspian sea connected with water balance change owing to increase of the river runoff (30 % from average long-term value) and also decrease of evaporation value from it's surface as a result of the global climate change.

At present, there are not reliable methods for forecasting the expected changes of the level of the Caspian sea. It makes it difficult to find a solution of the practical questions, connected with economic and economy in the sea basin. The elaboration of long range forecasting of the Caspian sea level is the actual problem of present time, connected directly with forecasting of climate in the vast territories of our planet. However, the analysis of historical materials and actual facts resulting from long-term observation permit to assume that in the nearest years the sea level will rise some more by 1.0 m. and in 2000 will reach the -26, 0 m. abs. level with deflexion  $\pm$  0,6 m. or will approach at the middle sea level, which took place in 1730-1930.

At present, problems connected with flooding of the coastal belt territories are very serious for Caspian countries.

In 1978-1992, 40,0 thousand km<sup>2</sup> of border-land (1000 km<sup>2</sup>) on the territory of Azerbaijan was flooded along the perimeter of the Caspian sea. At present, about 50 settlements and 220 industrial enterprises, 18 km. of railway, 10 thousand hectares of grasslands, recultivated objects for 100 thousand people, highways etc, are exposed to flooding. The same situation was created in other Caspian countries.

According to the data presented by russian experts in the Russian Federation till 50 km of the land region, 9 cities and 23 settlements, about 100 live-stock farms, 850-950 thous. hectares of the agricultural lands, 470 km railway and motor ways.

Flooding are exposing. The large oil-fields are exposed to flooding in Kazakhstan, 480 electro-transmission lines, 120 km motor ways, 594 thous. hectares of the lands, more 30 settlements get to the flooding zone. 15 settlements get to the influence zone in Turkmenistan, moorage-shipment buildings engineer communications (30 km), large gas and oil-fields.

In connected with sea level rise at the last year, increase danger of the wing set-up. Most damage noted at the northern part of the sea on the Russia and Kazakhstan territories south part of the Azerbaijan coast, south-east part of the Iran and Turkmenian coasts.

Modern sea level increase as a result of wind set-up on 1,5-2,0 m. and coastal zone at the northern part flooding at 30-40 kilometres distance, on the Azerbaijan coast 2,5-6,0 km.

In the present time in connected with Caspian sea level rise delta destruction of the r.Volga, Terek, Sulak, Samur, Kura, Sefidrud and that do the damage to it's rivers ecosystem.

Total area of Kura delta in comparison with 1977, decreased on 60% ( Fig.3).

Except flooding, observing level rise of the groundwaters that leded to bogging up and salting lands of the low-lying territories at the south sea coast, where situated the humid subtropics of the Azerbaijan and Iran take plate salting of the groundwaters.

In the future, the problems connected with flooding will complicate the socio-economical and ecological situation in the Caspian countries. Only in Azerbaijan, it is forecasted that the flooding of territories will increased by 800-900 km<sup>2</sup> and along all perimeter of the Caspian sea approximately by 20-25 thousand km.

The some actual ecologic problems of the Caspian sea are connected with the sea level rise. On the whole, the problems of ecology of the Caspian sea have an anthropogenic character: the society itself is it's source and victim.

The ecological state of the Caspian sea depends directly on the work of the industrial enterprises, urban economy, situated on the coastal belt of the sea, and also depends on the refuse and degree of the pollution of the river waters, flowing down in the sea. On the whole, the sea rise level as a natural phenonenon has a positive influence on the ecology of the sea, but in relation with flooding of the coastal belt territories, there is an ecological danger of pollution of the shallow regions of the sea with the refuse waters, oil products etc. Included, there are the regions of oil extraction and production of chemical industries.

On the high parts of the coasts take place the abrasion processes. Depending on situation and high of coasts the abrasion speed change from 5 to 100-120 m a year.

At the gas and oil-field regions and disposition of the chemical industry created the serious danger of the sea water coastal pollution.

At the following table showed of the hydrological and natural protection departments of the Caspian countries for spill of the chemical and pollution matters together with river runoff in the Caspian sea in 1992.

River	Annual runoff of the chemical matters mln.ton	Runoff of the matters pollution thous.ton.				
		oil-products	phenols	detergents	copper	zinc
1	2	3	4	5	6	7
Volga	60.0	145.0	1.20	3.10	1.60	7.10
Kura	5.0	1.3	0.10	0.40	0.10	0.10
Terek	3.0	0.1	0.01	0.10	0.02	0.04
Ural	2.5	0.6	0.10	0.27	0.27	1.62
Sulak	2.0	0.1	0.01	0.10	0.02	0.03
Samur	1.5	0.1	0.01	0.01	0.01	0.01

Analyze of these data shows that part of Volga from total quantity chemical matters that flow in the Caspian sea by water flow of the basic rivers consist about 84%, and matters pollution above 92%.

A large number of the waste water are flow by industries in the Caspian sea. According to the data of the water-protection organizations of these countries in 1992, was flow 6799 mln.m<sup>3</sup> of the waste water in the Caspian sea, and also at the Russian Federation, 3423 mln.m<sup>3</sup>, Azerbaijan Republic, 1708 mln.m<sup>3</sup>, Turkmenistan, 13 mln.m<sup>3</sup> and Kazakhstan Republic, 1655 mln.m<sup>3</sup>.

According to the results of the number biomass observations and species variety of the benthos on the picture showed of the Caspian sea ecosystem.

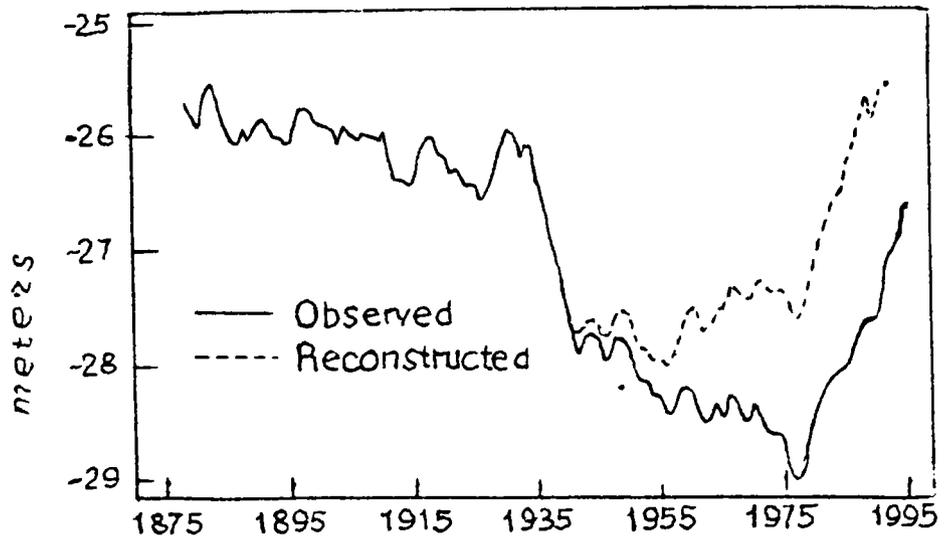
Decision of the Caspian sea problems, elaboration of the effective measures may provide with truth and timely information about intercommunication processes on the all resersoir and it's pond. It is possible in conditions of reliable functioning of the National Hydrological and Ecological network observations.

Modern station networks and ship observations of the Pre-Caspian countries at present time is degrading. For the last five years volume of the monitoring observations decrease on 1/3, base of technical means was used up on 80%, destroyed interaction system between countries. Therefore with a view stave off pollution and the Caspian sea level rise and it's environment protection it is necessary to combine efforts of the Caspian region countries under the leadership of the international organizations.

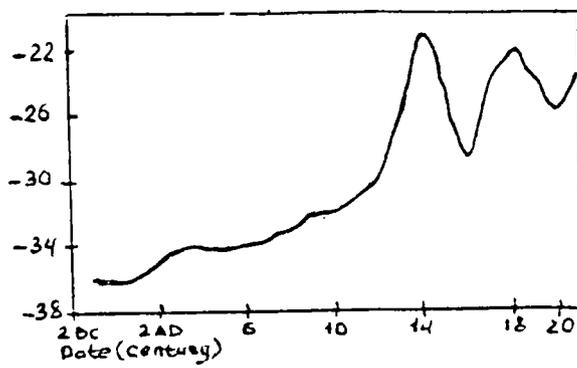
Basic tasks:

- (i) preservation and development on the more modern technical level of the stationary and expeditionary observations before functioned of the Hydrometeorological monitoring system and Caspian sea monitoring pollution, carry out of works for improvement of the observation systems;
- (ii) working out and organization the long-term international complex monitoring of the Caspian on the basis of national monitoring systems;
- (iii) preservation and development of effective mutual exchange of operative and regime hydrometeorological information with observation posts and between hydrometeoservices of the countries of the Caspian region, as well as the materials of expeditionary and scientific research works;
- (iv) working out and realization of regional international project (programme) of the Pre-Caspian countries for the Caspian under the aegis of international organizations;
- (v) creation of the regional data bank;
- (vi) joint actions in carrying out the scientific-practic conferences, meeting, seminars, training of personnal and oth.

Fig. 1.



Water-level variations in the Caspian Sea from 1875 to 1994



Fluctuations of water-level in Caspian Sea over the centuries

Fig. 2. Relative transference of the Caspian Sea level posts

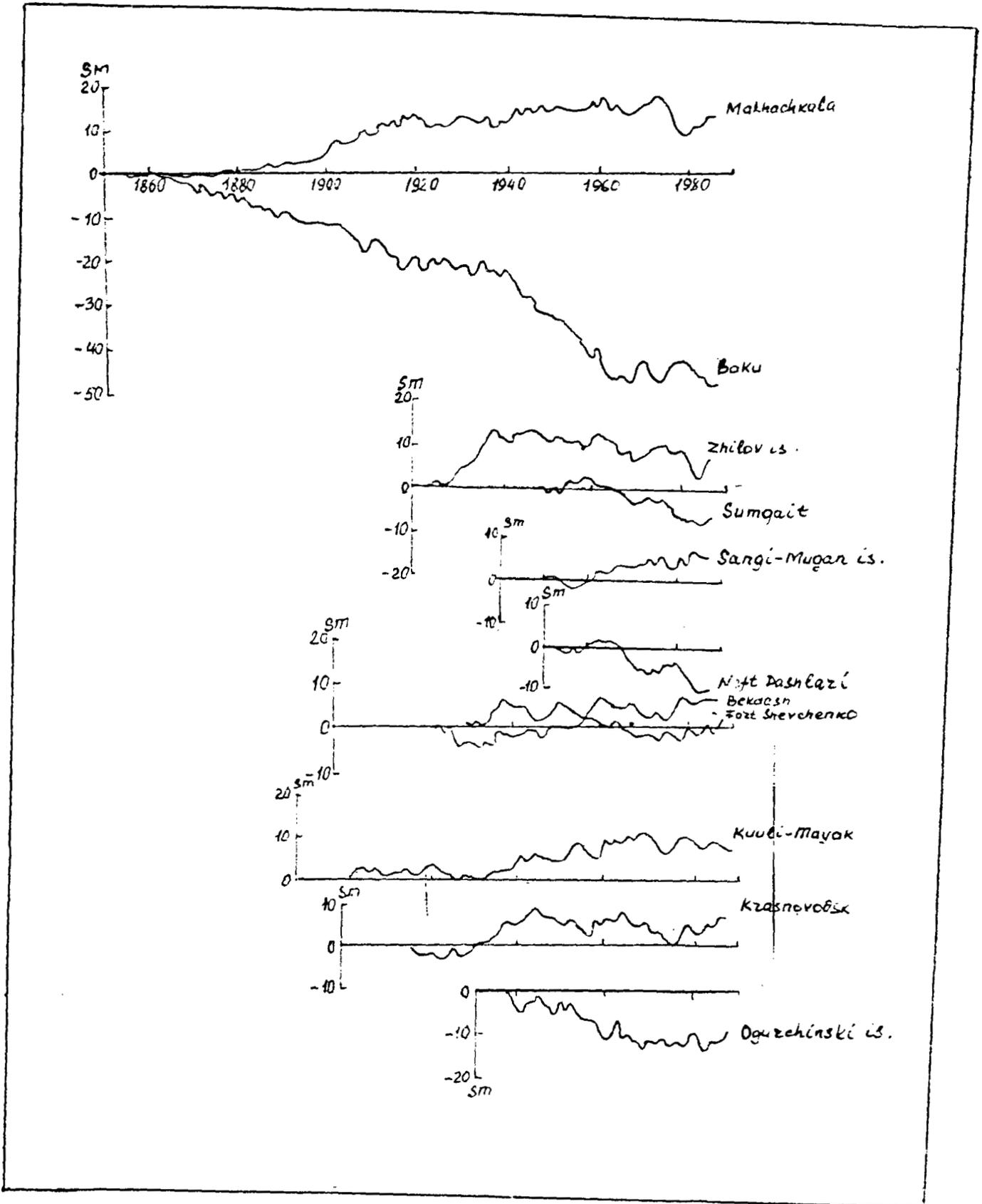


Fig. 3. Caspian Sea shore dynamics  
 (mouth of r.Kura - Astarinsk zone - 1977-1994)

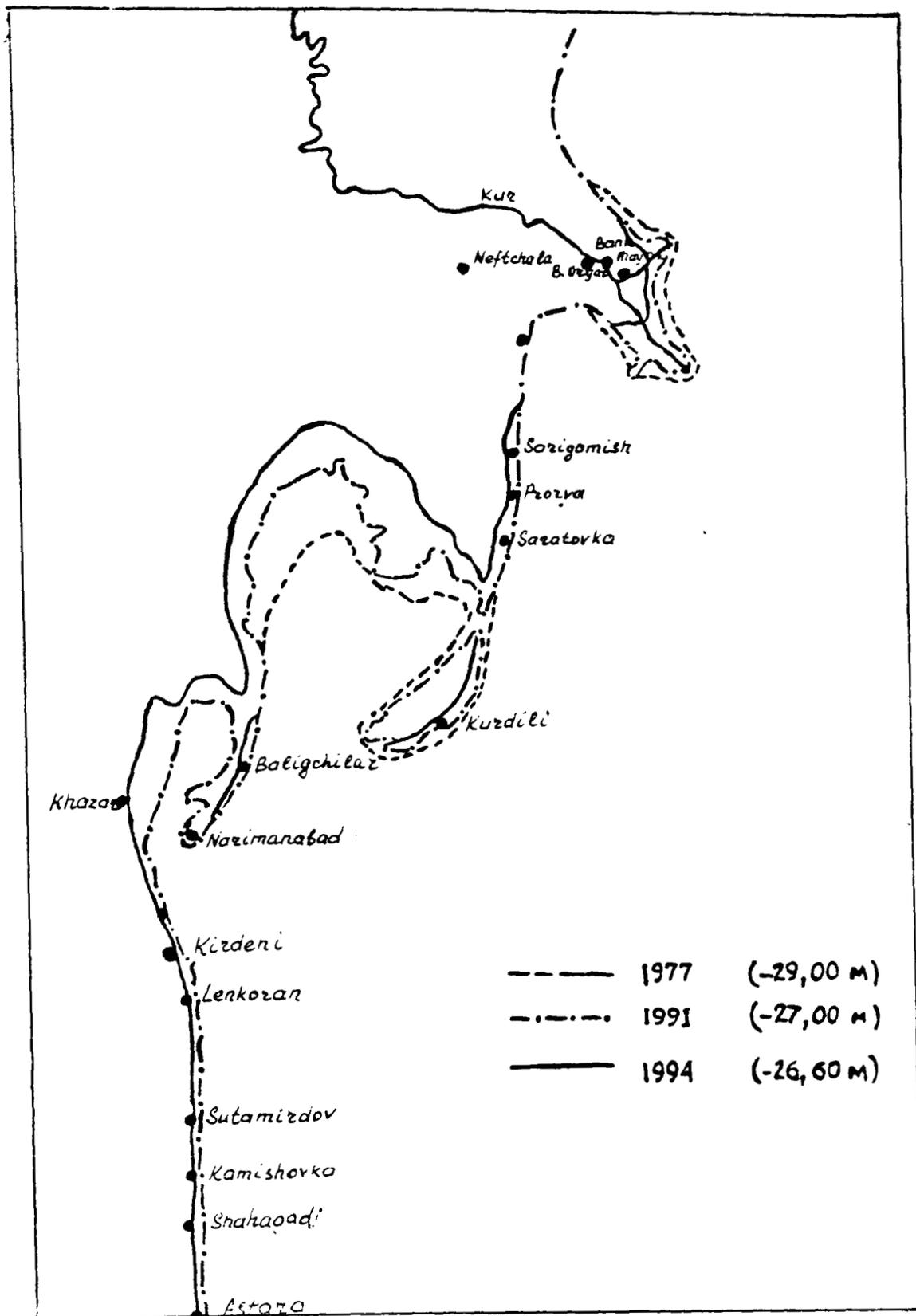
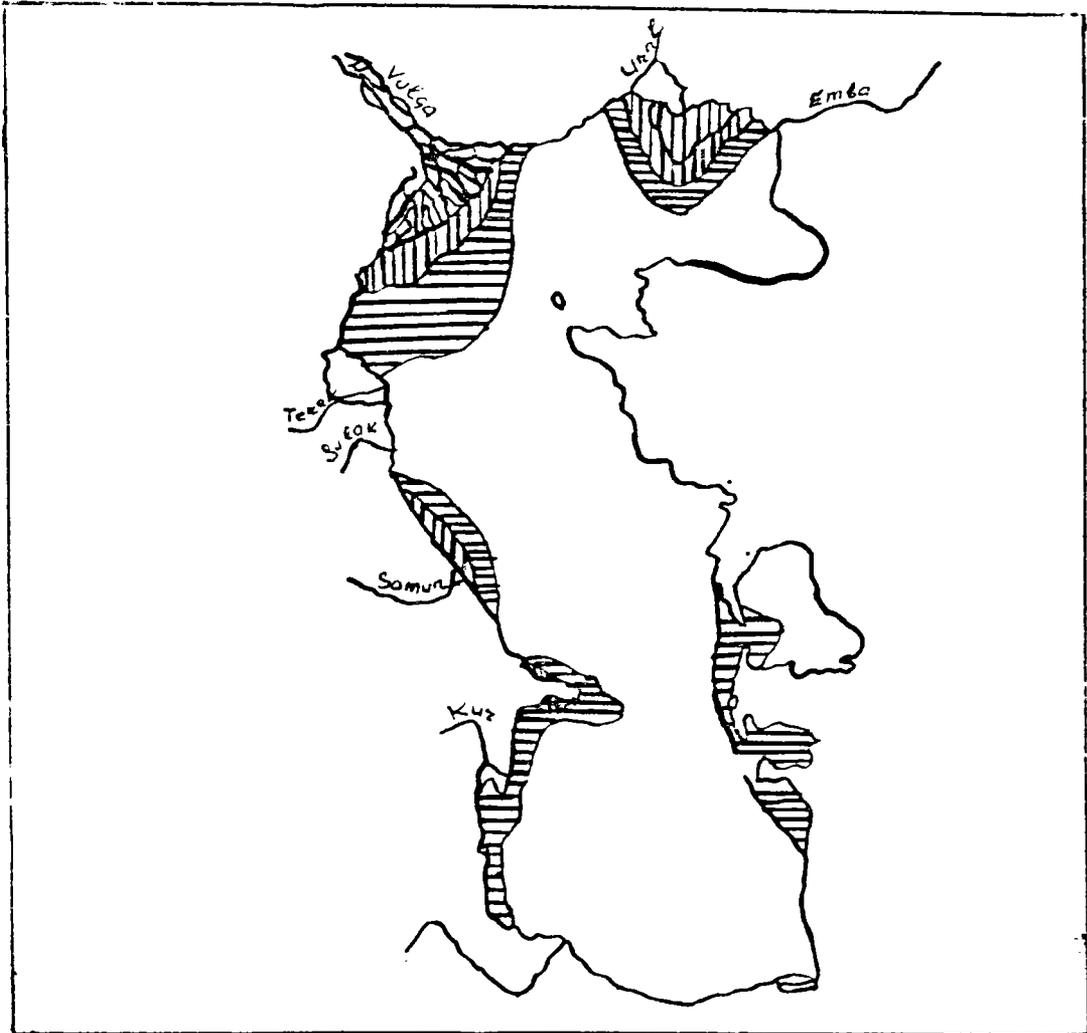
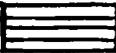


Fig. 4. State of the Caspian Sea ecosystem



-  - stable
-  - transitional
-  - critical
-  - catastrophical

**CASPIAN SEA LEVEL RISE  
AND ASSOCIATED ECOLOGICAL AND SOCIO-ECONOMIC IMPLICATIONS  
IN THE CASPIAN SEA COASTAL AREA OF TURKMENISTAN**

D.M. Gurbanov  
National Co-ordinator  
on the Caspian Sea Problems of Turkmenistan

Ladies and Gentlemen,

Allow me on behalf of the Government of Turkmenistan to express heartfelt and sincere thanks to those who have made this meeting possible for the opportunity to have a wide-ranging exchange of opinions and to take specific decisions on the transgression of the Caspian Sea.

The President, Saparmurat Turkmenbashi, and the Government of Turkmenistan are making considerable efforts to alleviate the harmful consequences of the rise in level of the Caspian whilst maintaining its biological diversity and generally protecting the sea's environment.

At the same time, numerous ecological and economic problems have built up in all the countries of Central Asia and any real help here from international and governmental organizations on any project, particularly those concerning the problems of the Caspian, would be most timely.

*In recent years, a difficult situation has arisen on the Turkmen shore of the Caspian due to the considerable rise in sea-level which has seriously affected the environment, particularly the low-lying parts of the land stretching from the Kralnovodsk gulf in the north to the border with the Islamic Republic of Iran in the south. The threat of flooding to vast stretches of land is becoming a serious impediment to the economic and social development of western Turkmenistan. Even now, on the south Cheleken spit, Dervish is in the process of becoming an island and buildings and structures in the lower part of the town of Cheleken and the village of Karagel are rapidly being submerged. Water has covered the Nebit-Dag oil workers' holiday resort on Cape Kheles and all lines of communications have been submerged, the foundations of electricity sub-station, pipe-lines and water mains to the left of the Koturdepe-Cheleken highway. Flooding has begun to affect the large oil and gas deposits of West Cheleken, Komsomol'sk and Koturdepe. Sea-water pollution by oil products has been observed as a result of upsurges and downsurges from oil storage depots, wells and dumps and considerable erosion of steep shores is taking place.*

A look at the history of the Caspian shows that from 1978, the rise in sea level has been part of the Caspian basin's regular transgression phase. On subsequent occasions when the sea level rose, the waters of the Caspian covered first of all the low-lying land occupied today by new Caspian sedimentation, around the Krasnovodsk and Turkmen Gulfs, and the estuary part of the "dry" river-bed of the Uzboi right up to the town of Nebit-Dag. The change from regression to transgression has led to a change in the shore's underwater incline and consequently in the geological and geomorphologic processes. Peneplain and abrasive-accumulative forms of relief have begun to replace accumulative shores.

The Caspian is a flooding territory without a well-defined coastline, with numerous tongue-like inlets, between which submerged wet marshlands tracts have formed. The groundwater level has also risen. Significant damage to the shore is being observed on the Okar-Kamishldzhinskii section, where abrasion is changing the underwater shore incline, formed of quaternary rocks, and the coastline itself is gradually moving east towards the original shore which was once a cliff. In 1993, in the west Cheleken area, the sea began to undermine the original shore and after a lengthy continental intermission formation of the cliff began again. Cracks are appearing in the surface of the coastal area, contributing to the formation of landslips and landslides, which is creating a serious threat to the exploitation of coastal wells and other facilities.

It would be possible to give a far greater number of similar examples.

It must be pointed out that there is no monitoring of the seasonal and annual dynamics of the region's landscape.

The rise in sea level is having a serious effect on an environment which had begun to change due to genuinely natural processes.

Measures taken to improve quality and effectiveness, and at the very least to maintain the parameters at their previous level, are not having the expected results. In addition, land used in the national economy is being flooded and, because of its pollution, is having its own pernicious effect on the waters of the sea. To halt this process, technical work is needed to clean the flooded land of products resulting from economic activity. Seventeen thousand tons of household and industrial waste will have to be removed from an area of 2,658 hectares. For this work to be carried out we will need 14.3 million manat.

It is no secret that in recent decades there has been considerable industrial development in the Caspian basin, with large-scale construction for power, hydrological and land reclamation purposes, the opening-up of new oil and gas fields and the continued exploitation of existing ones. While this has been going on, environmental requirements have not been fully observed, with the result that there has been a sharp increase in marine pollution due to human activity. Most of the pollutants that slip past human controls end up in the marine environment, causing both local and regional marine pollution.

All of this has impacted badly on the level of the herring, bream, wild carp and vobla (Caspian roach) catches. Only sturgeon is maintaining a fairly high level due to artificial breeding techniques. However, this has led to a mass outbreak of diseases among sturgeon such as dystrophy of the liver, a weakening of the roe membrane, etc.

In short, recent events of a natural and man-made nature are aggravating what would in any case be a difficult ecological and social situation throughout the Caspian states, including western Turkmenistan. The rise in sea level has led to and is continuing to cause the loss of developed land, production capacity and social infrastructure.

It is well known that the Turkmen shore has magnificent beaches, mineral springs and volcanic curative mud whose healing properties are not inferior to those of the mud of the Sakskii Lakes in the Crimea. The warm, sandy shore must be looked at as a future recreational asset of international importance. The climate means that the bathing season on the eastern shore of the Caspian is longer than on the Black Sea and the Sea of Azov. There is the unique Krasnovodsk reserve, established in 1932 to protect water-fowl and birds shore and to which every year up to 70% of all the birds which winter on the Caspian Sea come.

Unfortunately, the extensive use of natural resources without taking into account the consequences for the environment is continuing even now. Figuratively speaking, all the Caspian governments are stuck in the "*conquest of nature*" stage and what is needed is to take the next step "*living in harmony with nature*" that is, comparing the scale of industrial development with the expected burden on the natural ecosystem.

In conclusion, I would like to point out that the rise in the level of the Caspian Sea and the resultant flooding of a large part of the littoral has already caused substantial economic and social damage. Just today to mitigate and eliminate the consequences of the rising level of the Caspian will need 8,5029 million manat or US\$ 297.6 million.

A further rise in the sea level of 161.5 metres would have even more serious consequences. Large sections of the oil, gas and water pipe-lines would be flooded, the work of major industries in the towns of Turkmenbashi and Cheleken and the townships of Bekpash, Dzhangha and others would be threatened, and housing in coastal towns and settlements and social, cultural and health facilities would suffer considerably.

Unfortunately, up till now, the Caspian states have had no unified programme to stabilize the sea level. Independent attempts to protect facilities on the coast by carrying out coastal reinforcement works and constructing various kinds of embankments on separate parts of the coast can delay flooding only for a time.

Caspian water into the "dry" depressions with no outflow on the eastern coast, Kara-Bogaz-Gol bay (Turkmenistan), the Ashchi-Sor depression, Karagne, the eastern (and today dried out) part of Komsomolets bay and Sor Kaidak (Kazakhstan). This idea was put into practice in Turkmenistan in 1992 by the government decision, when the dam across the Kara-Bogaz-Gol strait was dismantled. As a result of the free entry of water, the bay has already taken in more than 80 km<sup>3</sup> of sea water, thus slowing the rate of the rise in level of the Caspian Sea by 6-8 centimeters a year.

A series of local measures should be aimed at protecting the most important facilities along the coast and at preventing pollutants from land within the potential flood zone from being carried down to the sea.

To obtain full information about the reasons for the fluctuation in sea level and forecasts the way it will behave, it is necessary to:

- (i) develop an intergovernmental programme for the Caspian States with the participation of international organizations (UNEP, UNESCO, WMO, World Bank and so on);
- (ii) set up an intergovernmental committee on the Caspian problem;
- (iii) establish aerospace, geological and geophysical monitoring of the behaviour of the coastline and changes in the geomorphological, tectonic and ecological situation.

It is also extremely important to have well-organized monitoring of the quality of the sea water and of environmental pollution and to study the biodiversity of the sea, equipping monitoring stations with up-to-date instruments and technological equipment.

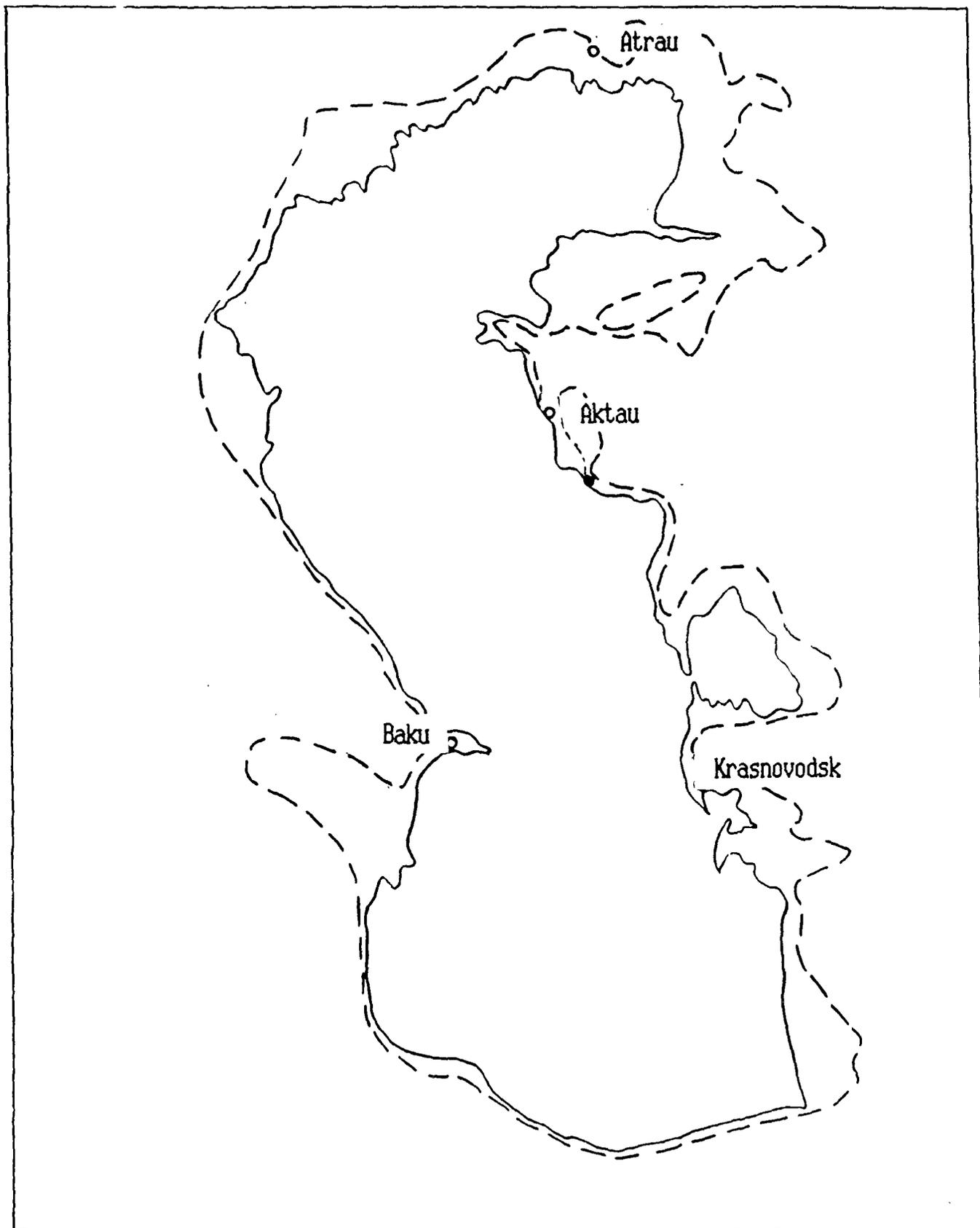
#### THE CASPIAN SEA WATER BALANCE

Periods (years)	Receiving part		Discharge part		Differences of the receiving and discharge parts cbkm
	River runoff cbkm	Precipitation cbkm	Evaporation from water surface cbkm	Runoff to the Kara-bogaz-gol bay cbkm	
1	2	3	4	5	6
1900-1929	330	70	389	16	-5
1930-1941	269	73	395	13	-66
1942-1969	285	74	356	8	-5
1970-1977	240	88	375	6	-53
1978-1991	307	86	343	0	50
1992	284	93	346	13	18

THE CURVE OF ANNUAL MEANS OF WATER LEVEL FLUCTUATION  
CASPIAN SEA - g.st KRASNOVODSK - 1915-1993 y.y.



THE SCHEME OF SUBMERGING ZONES OF CASPIAN'S SEA COAST  
TILL 2000 YEARS



**CO-ORDINATION OF THE TASKS TO BE CARRIED OUT IN IRAN  
IN CONJUNCTION WITH THE INTERNATIONAL-REGIONAL MULTIDISCIPLINARY  
ON CASPIAN SEA**

R. Khazaneh  
Scientific Advisor  
Atomic Energy Organization of Iran

Distinguished delegates,

In the name of the Atomic Energy Organization of Iran, I extend my sincere thanks to the International Organizations, specially IAEA and UNESCO for setting up the present Workshop. According to information provided to us from IAEA in December 1994, this Workshop was to be organized in Teheran with co-operation of UNESCO's Oceanographic Commission; so it was a surprise to us when we heard of its being held in Paris. The information reached us very late and we did not have enough time of the preparation of the present Workshop. But now that we are in Paris, we will try our best to exchange information and set up schemes for the very important project of the Caspian Sea studies especially the problem of the sea level rise. We are happy that International Organization such as IAEA, UNESCO, UNEP, WMO, WHO as well as the five riparian countries of the Caspian sea are represented here to start this co-operative work.

As you may know the two northern provinces of Iran namely Mazandaran and Guilan, have suffered from the sea level rise. These provinces, because of their suitable climate and abundant rainfall, count among Iran's best agricultural and horticultural lands and serve also as favorite places for tourism and recreation. The sea level rise in the last 16 years has caused extensive damages to the cities, villages and the shore boarding the sea in the following ways:

- (i) Damage to building and households specially in the lower cities of Bandar, Anzali and Tonekabon;
- (ii) Penetration of the saline water of the sea in the rivers basins as well as in the underground waters;
- (iii) Damages to power plants, industrial and fisheries installations;
- (iv) Narrowing and in some places completely destroying the public sea strands all along the sea coast;
- (v) Direct damages to the agricultural land on the sea shore used merely for fruit and vegetable production.

Figure 1 shows the fluctuation of the Caspian sea water level, relative to the Baltic sea, as measured by Russian and Soviet authorities from 1840. The level at the present time is about -26,5 m.

The Iranian authorities at the Caspian sea consider that any land and housing below -24 m are at high risk. By turbulent weather and sea storm, the sea level may increase by several meter and cause damage to the properties.

Figure 2 shows the high risk of damage to the properties in the province of Guilan. At the level of -24 m 1161 hectares of city's lands are at risk as well as 4900 houses and buildings. At the level of -23, the corresponding numbers are 314,5 and 2222. It should be added that in this province 2500 hectares of rice paddies have been damaged of which 500 hectares cannot be recovered because of penetration of saline sea water.

Figure 3 shows the fluctuation of the water level as measured by the Russian and Iranian authorities in the past 60 years. It shows a satisfactory harmony between the two independent measurements.

The difference of about 70 cm between the two curves comes from the fact that the Russian measurement is relative to the Baltic sea and the Iranian relative to the Persian Gulf.

As the sea level is steadily rising, the countries around the Caspian sea are becoming increasingly aware of the destructive power of this natural disaster. With oil and gas field, refineries and pipe line installations being developed in the region, the ecological dimension of the phenomenon is also becoming more important.

Since many years the Islamic Republic of Iran has sought co-operation among the riparian countries of the Caspian sea facing same problems as Iran. Iran has signed several bilateral as well as regional co-operation agreements with the Russian Federation, Kazakhstan, Azerbaijan and Turkmenistan at the ministerial level. These agreements concern many fields of activity including the subject of Caspian sea. We think however that because of the urgency and importance of the Caspian sea problems, special co-operative schemes have to be devised among the 5 riparian countries with the assistance of the International Organizations to tackle these problems.

We sought first the assistance of the International Atomic Energy Organization on the subject about a year ago. IAEA has issued in July 1994 a document outlining the scope and objectives of a project. In September 1994 we welcomed the visit of a delegation from this organization and Oceanographic Commission of UNESCO in Teheran. During this fact finding visit, which followed visits in the 4 other riparian countries, we had the opportunity of exchanging information between IAEA team and representatives of some Iranian organizations directly concerned about the subject.

IAEA team promised to seek a co-operation mechanism among some International Organizations, including their possible financial contributions, and forward a detailed proposal to us. We have waited a long time until the present Workshop is finally organized.

In November 1994, the Atomic Energy Organization of Iran has organized a meeting with the Iranian organizations and agencies to discuss the subject of this co-operation. Following is the list of the organizations which have declared their support and will co-operate in their respective field of activity with the project:

- (i) Ministry of Energy, Department of Water Resources is directly concerned and responsible. It will co-operate for sampling and supporting activities all along the sea shore through the Regional Water Board of Mazandaran. The ministry can provide also financial support for the project but expects training of technical personnel and a short time schedule for the implementation of the project;
- (ii) Water Research Center in Teheran has adequate laboratories (low level tritium and  $^{14}\text{C}$  measurements, Analysis of stable isotopes with mass spectrometer, hydrochemistry, etc). This Research Center is handling many research projects and studies related to water resources in Iran and could also assist taking the samples along the Caspian sea;
- (iii) Caspian Sea Research Center for water resources which is located in the city of SARI near the Caspian sea. This center has carried out several studies (one of which with the authorities of Russian Federation) and has collected documentation and data about the water level fluctuations arising not only from the steady sea level rise but also from the sea storms. This center can provide data and co-ordinate local logistic operations;
- (iv) Oceanographic Institute affiliated to UNESCO has extensive experience in the field of oceanographic studies. Since this institute is represented here through Dr. Partovian, I don't see the necessity to speak about their contribution to the project;
- (v) UNESCO's liaison office in Teheran has experience in co-operation between international organizations and Iranian governmental agencies. It can provide liaison activities with UNESCO and co-ordination among international organizations;

- (vi) Meteorological Organization of Iran affiliated to WMO can provide data about the meteorological situation in Iran and particularly in the Caspian sea region;
- (vii) Environmental Protection Organization of Iran has a network of measurements about air and water pollution. It has laboratories for measurements of organic pollutant among others;
- (viii) Iranian Fisheries Research Organizations has extensive experience about the fishery in Iran and specially in the Caspian sea. This organization has at its disposal a laboratory ship in the Caspian sea which can be used, on a part time basis, for sampling and measurement activities in the Caspian sea;
- (ix) Atomic Energy Organization of Iran (AEOI) is responsible for the peaceful application of the nuclear technology in Iran. This organization, with its qualified personnel and experts, diverse laboratories and a solid link with IAEA in Vienna can provide valuable assistance to the project.

Our main task could be to co-ordinate all the activities of the project in IRAN. Through a liaison office which would be set up very soon, AEOI has serve as the main link between the international organism or organizations directing the project from outside and the Iranian governmental and non-governmental agencies to the other. The co-ordination task of AEOI has been welcomed and supported by the representatives of all other Iranian organizations mentioned above in Iran. We are however flexible on this subject and according to the result of discussions that we will have here during this Workshop, other mechanisms of co-ordination could be devised for the implementation of this project in Iran.

At the end of this short presentation to the IAEA/UNESCO Workshop, I want to come to a conclusion. Different governmental agencies of Iran, all concerned about the problems of the Caspian sea, have approached international organizations for their assistance during the last years. Many meetings have been held and many documents have been issued. It is now time to begin to work, before millions of the people who live around the Caspian sea and who have suffered during the last years lose their hope in the competence and carefulness of the riparian government authorities and the international organization.

In the name of the Atomic Energy Organization of Iran, I wish full success for this Workshop and declare that my Organization is ready to assist in any possible way the implementation of this project.

Figure 1 - The variation of the Caspian sea water level relative to the Baltic sea from 1840.

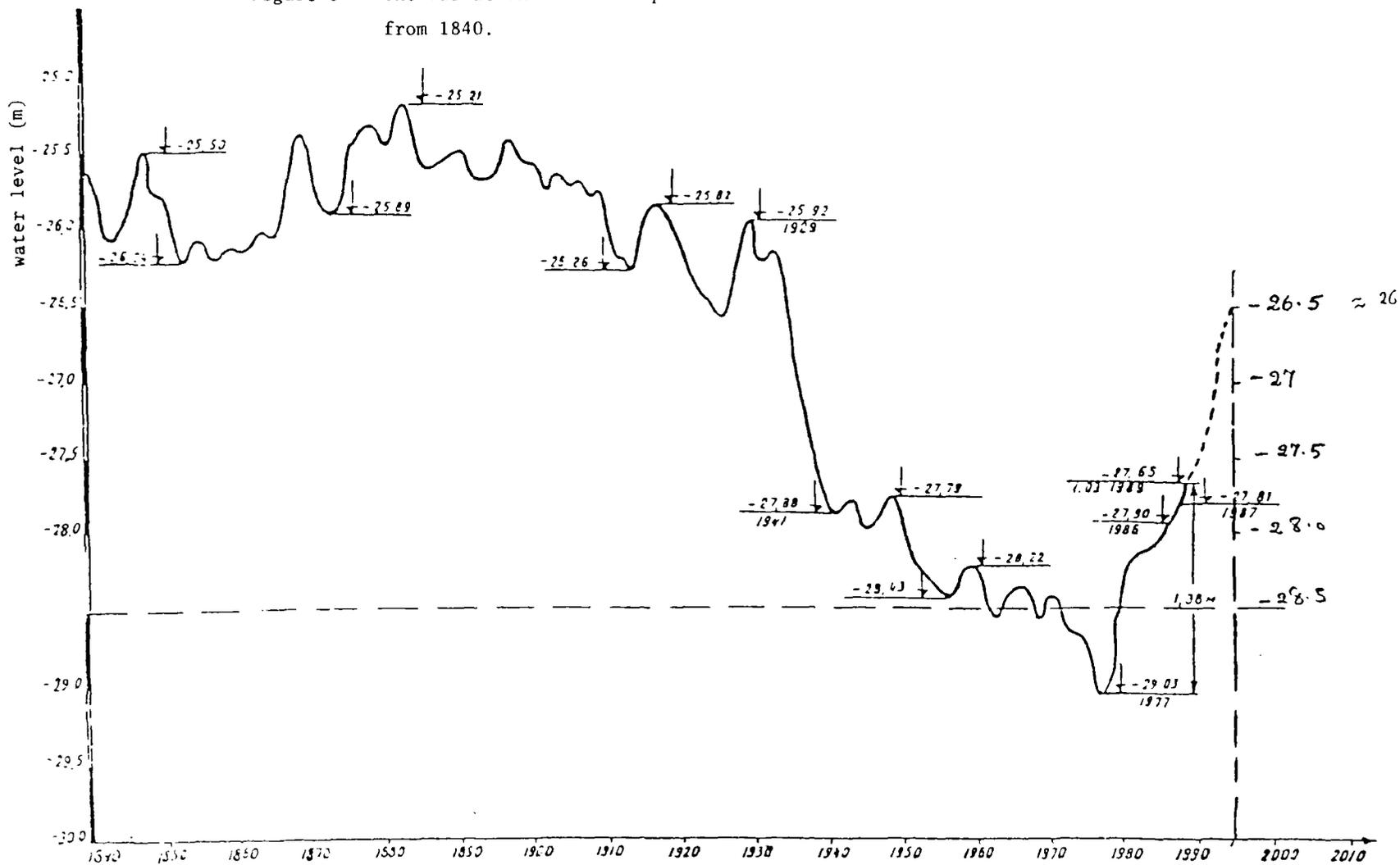


Figure 2 - The surface of cities and number of houses at different levels in the Guilan Province.

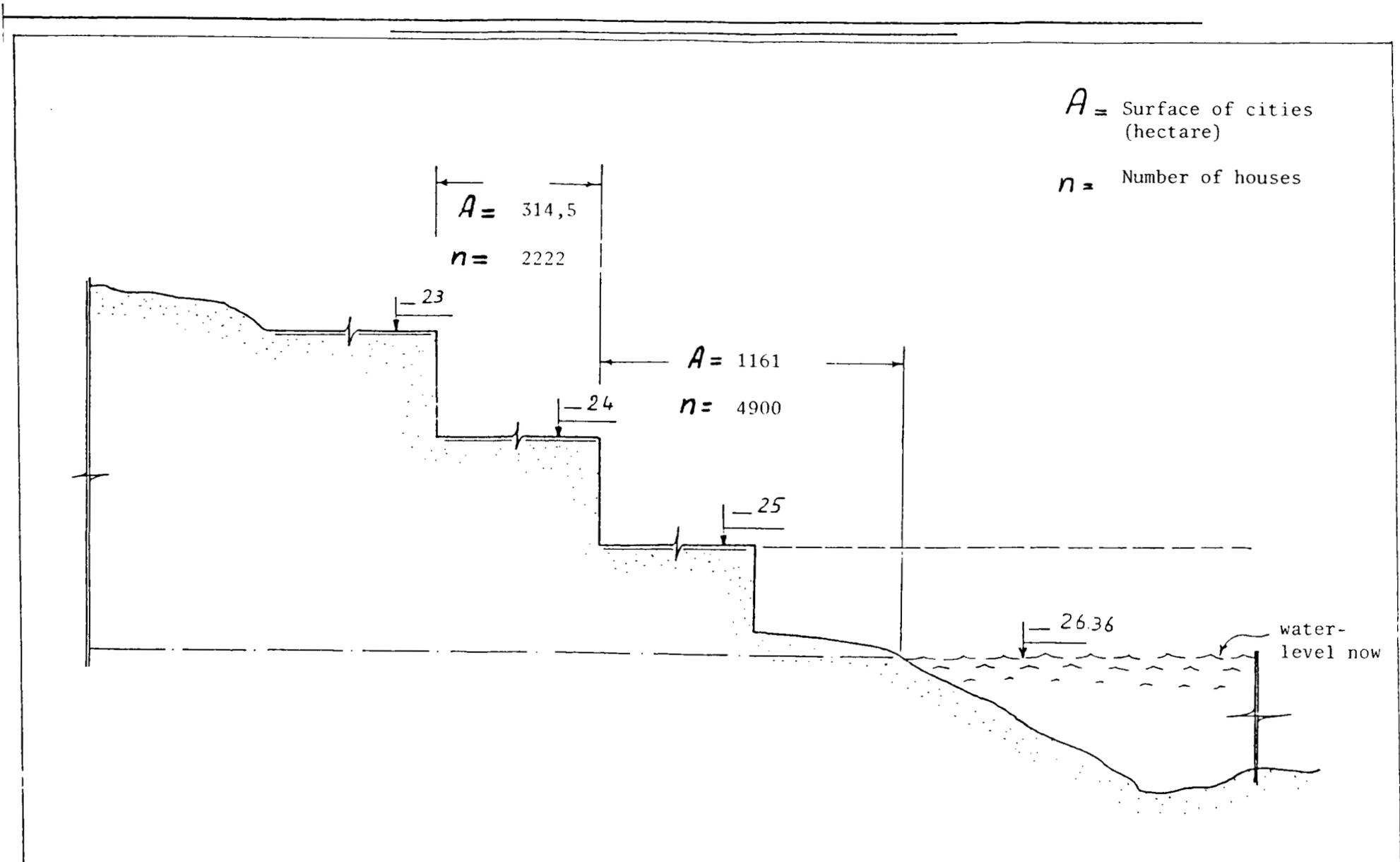
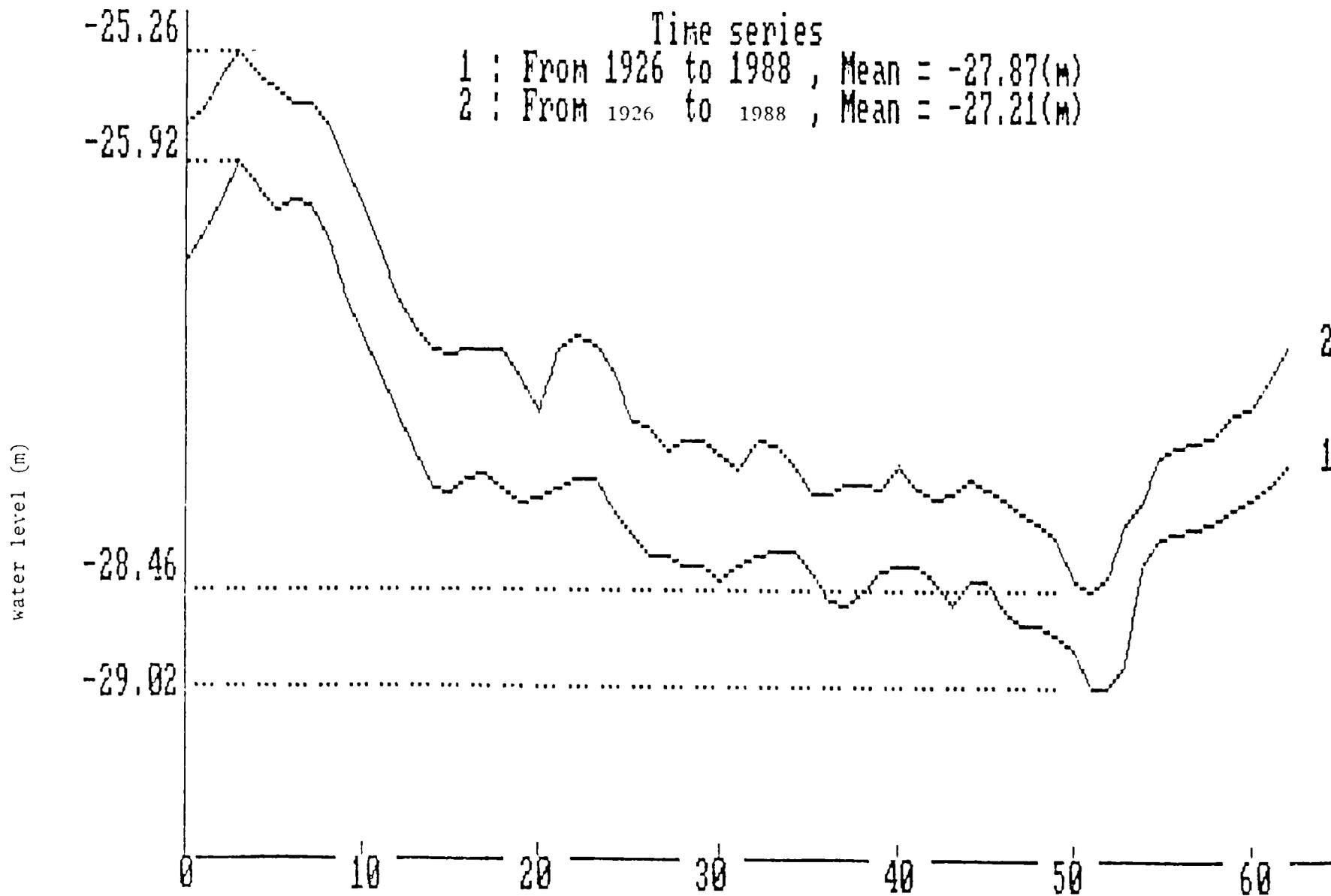


Figure 3 - Variations of Caspian sea water level since 60 years as measured by Russia (1) and Iran (2).



**REALIZATION OF THE INTEGRATED PROGRAMME  
ON HYDROMETEOROLOGY AND ENVIRONMENTAL MONITORING  
IN THE CASPIAN SEA BASIN**

**- A PRE-CONDITION FOR THE SOLUTION  
OF SOCIO-ECONOMIC AND ENVIRONMENTAL PROBLEMS IN THE REGION**

A.A. Maximov, Roshydromet  
A.V. Frolov, Hydrometeorological Center of Russia

It is well known, how vitally important the Caspian sea is for the sustainable development of the countries of that region : this is the nature-economic system developed during many years, very rich in oil and other natural resources. The region is also characterized by the unique biodiversity.

The distinctive feature of that region in recent years has become the existence of serious social, economic and environmental problems, caused by two major reasons:

- 1) the drastic rise of the Caspian sea level (2,3 m for the last 17 years);
- 2) the destructive of the USSR.

Here it is only some examples of the most severe problems in the Russian part of the Caspian sea coastal zone:

- (i) Wind-induced surges of the height up to more than 3 meters, spreading up to 20 km and more than 3 meters, spreading up to 20 km and more inside the coast. The last catastrophic surge occurred 13-16 of March, 1995 and 26 of March, 1995, when there was flooded the vast areas (including settlements) as the North-West and West of the Caspian sea, with the maximum level rise of 232 to 320 centimeters;
- (ii) Destruction of banks with the velocity of to 10 m/year;
- (iii) Flooding of lands with the velocity of 1-2 km/year, including flooding and underflooding of settlements, agricultural lands, irrigation systems, oil fields, roads, electric power lines, waste purification plants, etc.

As a result of flooding and underflooding it takes place the contamination of surface and ground waters by toxic substances (10 to 100 time exceeding limits) and by oil products, soil salinization and vegetation hydromorphization are progressing, the conditions for safe drinking water supply are worsening. The danger of infections (cholera, plague) is increasing. Outbreaks of skin, allergy and other diseases are quite often take place;

- (iv) Reserved territories are destroyed;
- (v) The loss of high productive spawning places of valuable fish is increasing in the Volga delta, the catch of that fish is drastically declining.

Similar problems take place in other Caspian countries.

In those conditions, naturally, at the national and local levels considerable efforts are taken in order to develop and realize measures, aimed at the solution of social, economic and environmental problems, connected with the drastic level rise of the Caspian sea.

However realization of those measures faces considerable difficulties, first of all, such as : financial and economic, which are typical for the Caspian sea countries -the former republics of the USSR; legal, connected with the uncertainty of the international legal status of the Caspian sea. One of the major hindrances for the solution of the Caspian sea problem is a very inadequate understanding of the nature of drastic sea level rise phenomena, the impossibility to give a reliable short-term,

medium-term forecast of the sea level change. Another reason is the destruction of the existing in the Goscomhydromet of the USSR united for the whole Caspy system for hydrometeorological monitoring and monitoring of environmental contamination in the region.

The absence of the reliable forecasts leads to non adequate management and technical decisions and to non rational large capital investments. In its term, the absence or non adequate observation system does not allow to develop a reliable forecast of the hydrological regime of Caspy and of its environmental state.

The Government of Russia with due account of the comprehensive character of the Caspian problem has charged various ministries to provide the development and realization of measures to solve that problem. Along those the Federal Service of Russia for hydrometeorology and monitoring of environment was charged with the following duties:

- (i) to conduct scientific studies for forecasting the Caspian sea level rise;
- (ii) to give hydrometeorological provision to design, construct and operate protection engineering hydrotechnical structures;
- (iii) to work out and realize urgent steps to restore the network for hydrometeorological monitoring and monitoring of the Caspian sea contamination.

Why that work has been charged to Roshydromet ?

This is explained by the character of the activities of the Federal Service, aimed at hydrometeorological provision of the national economy and monitoring of environmental contamination, as well as at the scientific justification of those works.

In relation to the Caspian sea problem out of 20 research institutes of Roshydromet more than half of them are dealt with the research on various aspects of that problem. Among them:

- (i) State Oceanographic Institute (GOIN, Moscow) -marine,delta studies, monitoring of environmental contamination;
- (ii) Hydrometeorological Center of Russia (GMC, Moscow) -development of short-term, mid-term and long-term forecasts;
- (iii) State Hydrological Institute (GGI, Saint-Petersburg) -water balance studies, development of over long-term forecasts, climate impact on water resources;
- (iv) Main Geophysic Observatory (MGO, Saint-Petersburg) -development of scenarios of global and regional climate changes;
- (v) Institute of Global Climate and Ecology (IGCE, Moscow) - hydrobiological monitoring and hydrobiological studies;
- (vi) All Russian Research Institute of Hydrometeorological Information -World Data Center (VNIIGMI-WDC, Obninsk town, Kaluga region) - hydrometeorological regime studies, information systems, data banks;
- (vii) Hydrochemical Institute (HCI, Rostov-on-Don city) -hydrochemical studies;
- (viii) Scientific-Production Agency "Typhoon" (SPA "Typhoon", Obninsk town, Kaluga region) - radiological contamination;
- (ix) Scientific-Production Agency "Planet" (SPA "Planet") -satellite hydrometeorological data and studies.

In order to realize the tasks charged by the Government, Roshydromet, its research and operational agencies have developed the proposals to the draft Integrated programme of the Caspian sea countries in the area of hydrometeorology and environmental monitoring of the Caspian sea and its basin. Russian scientists and specialists came to the conclusion, that only an Integrated programme in that field, which will logically combine efforts to study the key problem of the Caspian phenomena - the drastic rise of its level, with the restoration, rationalization and development of the integrated monitoring network in that region, will be able to establish a sufficient scientific and information bases for the solution of social, economic and nature protection problems in the Caspian region.

"*The Integrated programme...*" would make it possible, firstly, to use to the maximum extent, the results of studies and great experience (including negative ones) in that field, gained during recent decades, secondly, to integrate various fundamental and applied studies, being conducted at present at the local, national and international levels.

Proposals of Roshydromet to the "*Integrated programme...*" were adopted by the Russian Governmental Commission on the Caspian sea problems and after introducing the changes and proposals of related Russian ministries, have been sent to other Caspian sea countries as the Russian proposals to the above regional integrated programme.

The Russian proposals to the "*Integrated programme...*" are aimed at the solution of two major tasks:

**The first task** provides for the development of the interstate regional system of integrated monitoring of the Caspian sea region, which includes hydrometeorological monitoring on the basis of the rationalization and development of the existing hydrometeorological network, hydroecological and satellite monitoring of the Caspian sea and deltas of its major rivers.

**The second task** provides for to conduct studies to reveal the reasons for the drastic change of the Caspian sea level and to develop forecasts of its oscillations for various lead time.

#### I. **DEVELOPMENT OF THE INTERSTATE REGIONAL SYSTEM OF INTEGRATED MONITORING OF THE CASPIAN SEA REGION**

The solution of problems, dealing with revealing the reasons of the Caspian Sea level oscillations, forecasting its changes of various lead time, assessing the impact of the sea level rise on environmental conditions in the region are not possible without restoring and developing the system of integrated environmental monitoring of the Caspian region. Until recent years such system had been functioning in the structure of the former Goscomhydromet of the USSR. Of course, this system, which had been developed in the period of a relatively steady state of the sea level, with a falling trend, was not quite adequate for the needs of practice and science in the conditions of abrupt rise of the level, but it was also actually destroyed with the disintegration of the USSR.

The observation system of the USSR Goscomhydromet in 1991 consisted of 212 stations and posts in the region including coastal areas and the open sea. At all those stations during last 20 years besides hydrometeorological observations, there were made integrated hydrochemical observations, observations over the content of the dangerous pollutants, as well as hydrobiological observations.

The above research institutes of Roshydromet analyzed the information, received, assessed the current hydrological, hydrochemical and hydrobiological state, made forecasts of their possible changes, published information and methodic documents, scientific monographs and articles, organized and held all-Union meeting and conferences.

As a result of the Caspian sea level rise and in view of the liquidation of the USSR Goscomhydromet the most part of the observation stations and posts in the sea and at the coast have been destroyed, while at the functioning stations and posts the technical facilities for observations have become unfit for use; the wharf and open-sea depth gauges were damaged.

For example, at the Russian coast at present are functioning only 3 points of observation on the sea level, while only one of them is functioning satisfactory. In the mouth of Volga and Terek there is no one stationary sea level recorder.

The observation network in other Caspian sea countries of the former USSR is not better.

The pictures 1 and 2 show the present network of hydrometeorological stations and posts in the Caspian sea region. The information from those stations and posts is at present used for the solution of operational tasks and in regime studies.

In the table 1, it is shown the list of stations on the Caspian sea coast, from which hydrometeorological data come to hydrometeorological center of Russia (the state for 1994).

At picture 3, it is shown the scheme of location of the coastal observation points in the Caspian Sea (1991), at the picture 4 -the scheme of location of oceanographic stations on "secular" and standard sections and in roadstead points.

The existed in the former USSR Goscomhydromet monitoring system of hydrometeorological and oceanographic data in the Caspian sea region provided for, that the results of observations from research vessels, hydrometeorological stations and posts, buoys, aeroplanes, satellites were transmitted to the Hydrometeorological Center of USSR, mainly, for forecasting purposes, and simultaneously were directed to the All-Union Research Institute of Hydrometeorological Information-World Data Center (VNIIGMI - WDC, Obninsk town, Kaluga region) as regime data for processing, storage and supplying to various users.

The existing in VNIIGMI - WDC a Center of Oceanographic Data (COD), (which is one of the largest world centers for collecting, storage, processing and disseminating information on physio-chemical state of oceans, seas and adjacent atmosphere layers).

Has developed vast data bank on the Caspian sea. In the table 2, it is shown the state of the data file for many years oceanographic and hydrometeorological observations in the Caspian sea.

The development of the interstate regional system for integrated monitoring of the Caspian sea, proposed in the draft "*Integrated programme...*", should include the organization and modernization of the following kinds of observations and systems for collecting, processing and transferring the information to the users:

- (i) hydrometeorological, based on the development of the existing in the Caspian basin hydrometnetwork;
- (ii) hydrologic-morphological, based on the organization of special observations at the standard coastal and estuarine sections, and on the development of aerospace methods;
- (iii) hydrochemical, based on the development of available system for assessing contamination on the Caspian water surface and in the estuaries;
- (iv) hydrobiological, based on the available system for the assessment of the ecosystems' state on the Caspian water surface and in the river mouth;
- (v) satellite, including charting the Caspian water plane dynamics through the wind effected, seasonal and perennial changes in temperature, waves, direction and force of the wind, water surface pollution, sky conditions, ice cover, seasonal and perennial dynamics of the snow and vegetation cover in the drainage basin and the contours of the bottom vegetation (macrophytobenthos), charting flooding and morphological changes in the Caspian river deltas and coasts;

- (vi) a notification system for informing the population about dangerous phenomena, which lead to emergency situations and ecological catastrophes;
- (vii) a system of ecological forecasting of the state of the Caspian sea and the mouths of the inflowing rivers, and a support for making decisions at the national and international level of the Caspian countries.

The establishment of an integrated monitoring presupposes also an up-to-date information supply, including:

- (i) forming data bases and systems for the collection, control and analysis of information;
- (ii) monitoring products dissemination systems.

## II. STUDIES TO REVEAL THE REASONS FOR THE DRASTIC CHANGE OF THE CASPIAN SEA LEVEL AND TO DEVELOP FORECASTS OF ITS OSCILLATIONS FOR VARIOUS LEAD TIME

Within the framework of that task the Russian proposals have in mind to do the following works:

- (i) To reveal the role of individual factors in the sea level change and its causes in the last 15 years;
- (ii) To work out a system of forecasting the hydrometeorological regime from several days to 1,5 - 2,0 years;
- (iii) To study the impact of the sea level rise on the hydrometeorological regime and environmental situation in the sea, in the coastal zone and in deltas of major rivers;
- (iv) To assess the possible sea level in 10-20 years with due account of economic activities in the basin and of anthropogenic climate change.

It is worth mentioning, that the proposals to the "*Integrated programme...*" in its research part pay special attention to such questions as diagnosis of the Caspian sea water balance components, which is the basis for the long-term and over long-term sea level forecasting, to the assessment of the impact, made by climatic factors and water balance of the sea, as well as to generalization and comparative analysis of the existing climatic scenarios for the Caspian basin and its water surface for the nearest decades, obtained by the current models of general circulation of the atmosphere and with the use of paleoclimatic analogues.

Thus, as it is seen from the above tasks of the "*Integrated programme of the Caspian sea countries in the area of hydrometeorology and environmental monitoring in the Caspian sea and its basin*", proposed by Russia, their realization will be dealt with implementation of a big amount of research and operational works with the objective to establish the scientific and information bases, needed for the solution of socioeconomic and nature protection problems in the region.

It should be mentioned several more important characteristic features of the proposals to the "*Integrated programme...*":

- (i) Close interrelationship between the research and monitoring parts of the proposed programme. Realization of the research part, in the main, will not be possible without implementing works to restore and develop the monitoring system;
- (ii) The proposals were developed not only for the Russian part of the Caspian sea, but for the whole basin. The authors of the draft programme came from the provision, that the restoration of the monitoring network and conducting studies for forecasting sea level change are the problem of the whole Caspy and would be possible only with the participation of all Caspian countries;

- (iii) The "*Integrated programme...*" proposed by Russia, can be implemented within the existing legal conditions, when some questions of the Caspian sea legal status are not solved. The solution of problems in the field of hydrometeorology and monitoring of environment does not demand to include into consideration such legal questions, as marine borders of the Caspian countries, joint utilization of the Caspian sea natural resources, etc. The tasks, put in the proposed "*Integrated programme...*", could be solved within the framework of that "*legal space*", in which the World Meteorological Organization has been functioning during many years.
- (iv) The proposals to the "*Integrated programme...*" have also formulated the most priority works to be done in the nearest years.

The solution of the Caspian sea problem is to be of much importance not only for the Caspian sea countries; at present that problem becomes one of the world most important water management problems, arousing interest in many international organizations (WMO, World Bank, IAEA, UNEP, UNIDO, UNESCO, etc...). The indicated organizations are planning to conduct special research on the Caspian problem, and are working out corresponding scientific programmes. The analysis of these programmes has shown, that considerable part of the planned studies will be aimed at solving the hydrometeorological and ecological problems of the Caspian sea: the restoration of the network, pollution monitoring, study of the dynamics of various elements of water balance, etc... It is assumed in this connection that the Programme of the Caspian countries will be closely allied to the programmes of the international organizations. When forming the projects of co-operation with them, certain measures will be suggested in order to avoid duplication, to use at a maximum degree the scientific and technical potential of the Caspian countries, and thus utilize more effectively all the possible financial and technical aid of the international organizations in order to realize the proposed Programme.

TABLE 1. CASPIAN COASTAL HYDROMETEOROLOGICAL STATIONS (1994)

N	Index	Station	Period of observation (on GMT)	Type of observation in the kode KH-02 "Sea"
		<b>Russia</b>		
1.	37470	Derbent	06	Wind, visibility in the sea, water temperature, air temperature, sea level, waves, ice.
2.	37472	Makhachkala	06	
3.	37473	Izberg	06	
4.	37089	Tyleny island	06	
5.	34989	Island Iscusst-veny	06	
		<b>Turkmenistan</b>		-idem-
1.	38364	Bekdash	06	
2.	38367	Kara-Bogaz-Gol	06*	
3.	38504	Kuuly-Mayak	06	
4.	38507	Turkmenbashi(Krasnovodsk)	06*	
5.	38630	Cheleken	06	
6.	38637	Isl. Ogurchinsky	06	
		<b>Azerbaijan</b>	**	-idem-
1.	37769	Sumgait	06	
2.	37850	Baku	06	
3.	37861	Neftyanje kamni	06	
4.	37922	Island Svinoi	06	
5.	37925	Neftechala	06	
6.	37985	Lenkoran	06	
7.	37863	***	06	
		<b>Kazakhstan</b>		-idem-
1.	38001	Fort Shevchenko	06	
2.	35705	Peshnoi	06*	
3.	35907	Kulaly	06	
4.	38111	Aktay	06*	

\* Are to be transmitted to Hydromet center of Russia (Moscow) according to bilateral agreement, but data come irregularly;

\*\* There is no bilateral agreement between Roshydromet and Azgoscombydromet, but data sometimes come.

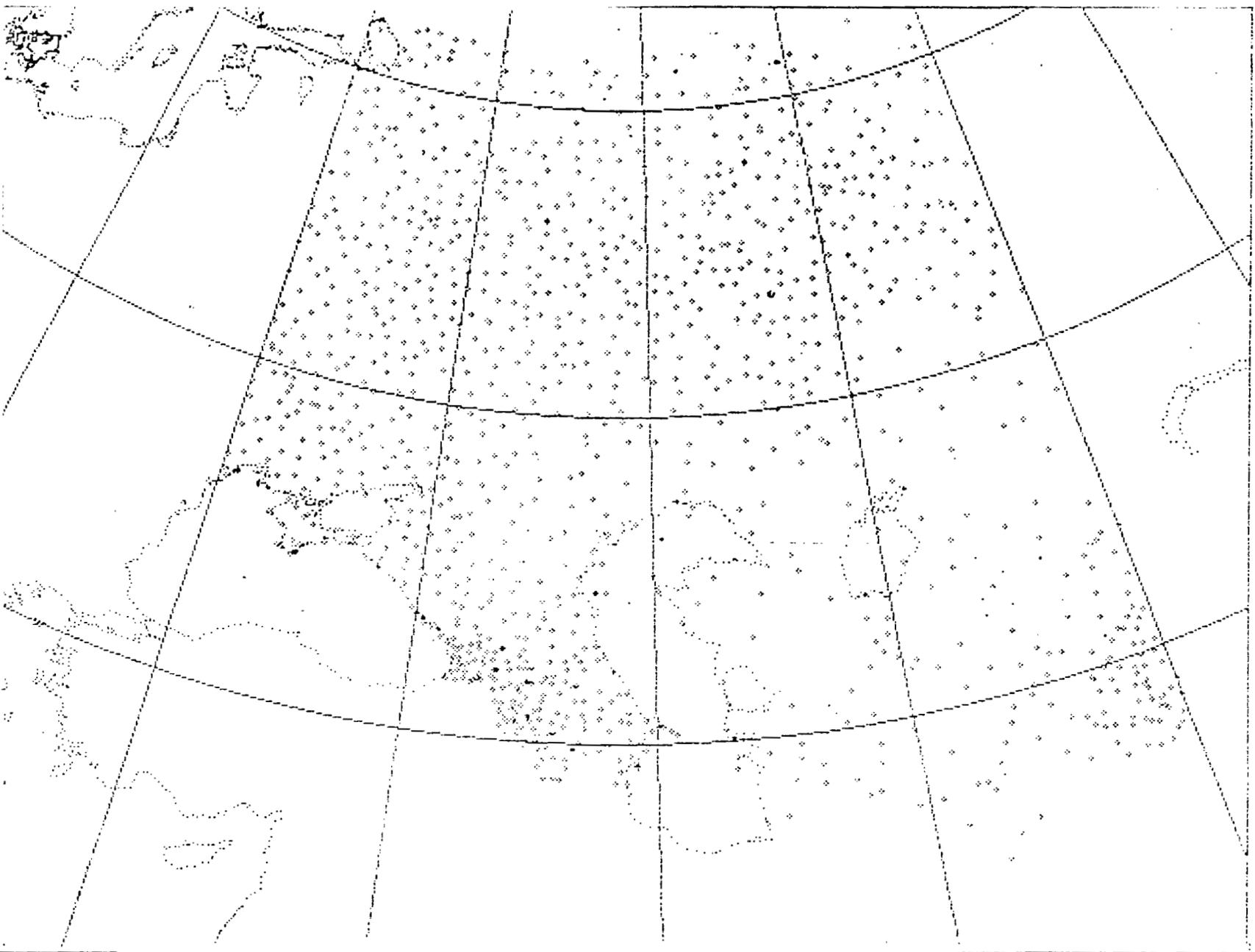
\*\*\* The name of the station is not known, but data sometimes.

**TABLE 2.**

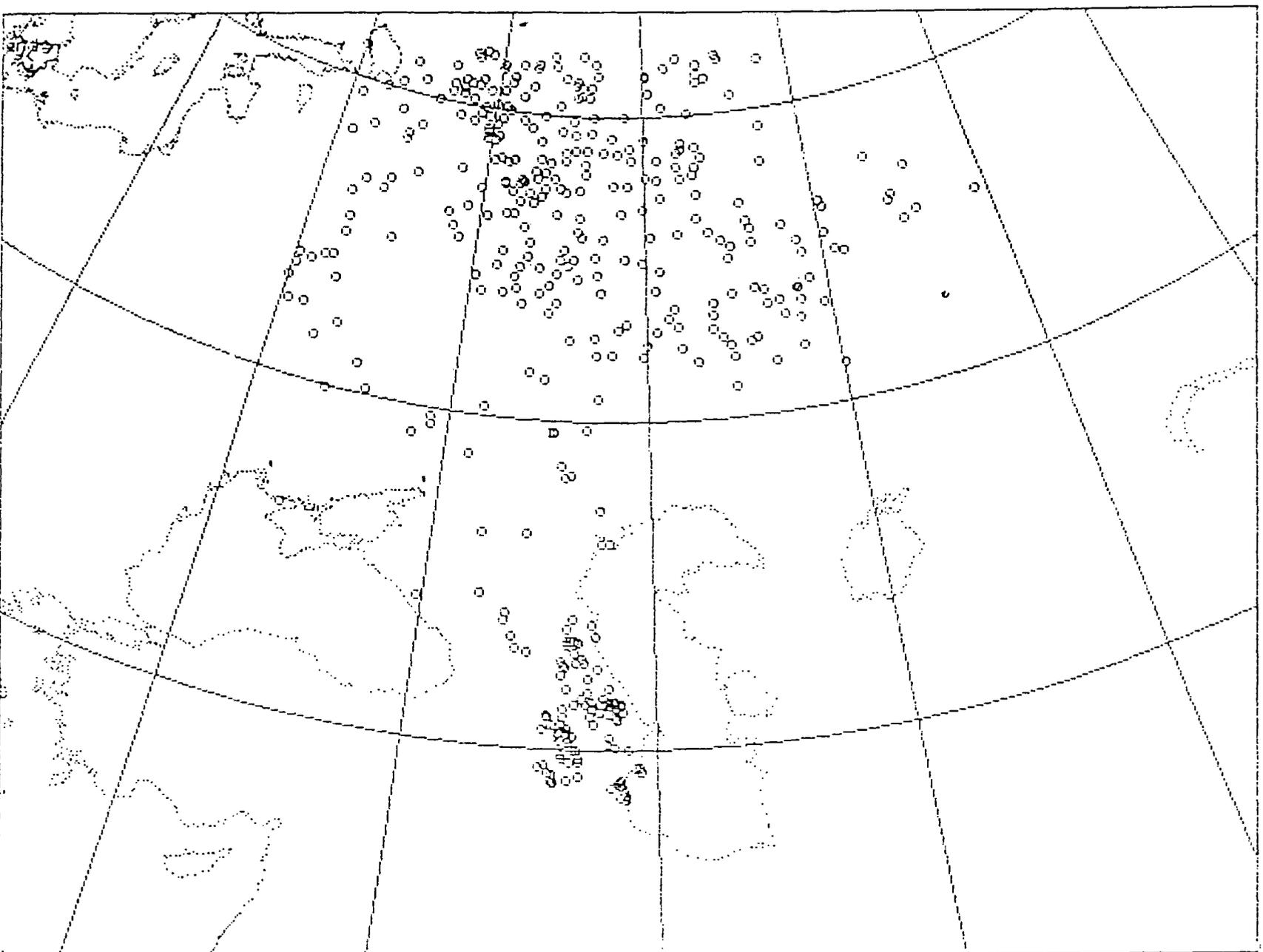
**The state of data file for many years oceanographic and  
 hydrometeorological observations  
 in the Caspian Sea**

Type of observation	Total amount of data		Availability in VNIIGMI-WDC	
	Amount	Period of observation	Amount	Period of observation
Coastal	36 stations and posts	1882-1992	36 stations and posts	1997-1992
Deepsea	5500 expeditions, 50 thousands observations	1907-1992	4200 expeditions, 40 thousands observations	1907-1992
Current	700-800 Autonomous buoys	1956-1992	300 Autonomous bouys	1958-1991
Vessels	350 thousands observations	19..-1992	249 thousands observations	1935-1992

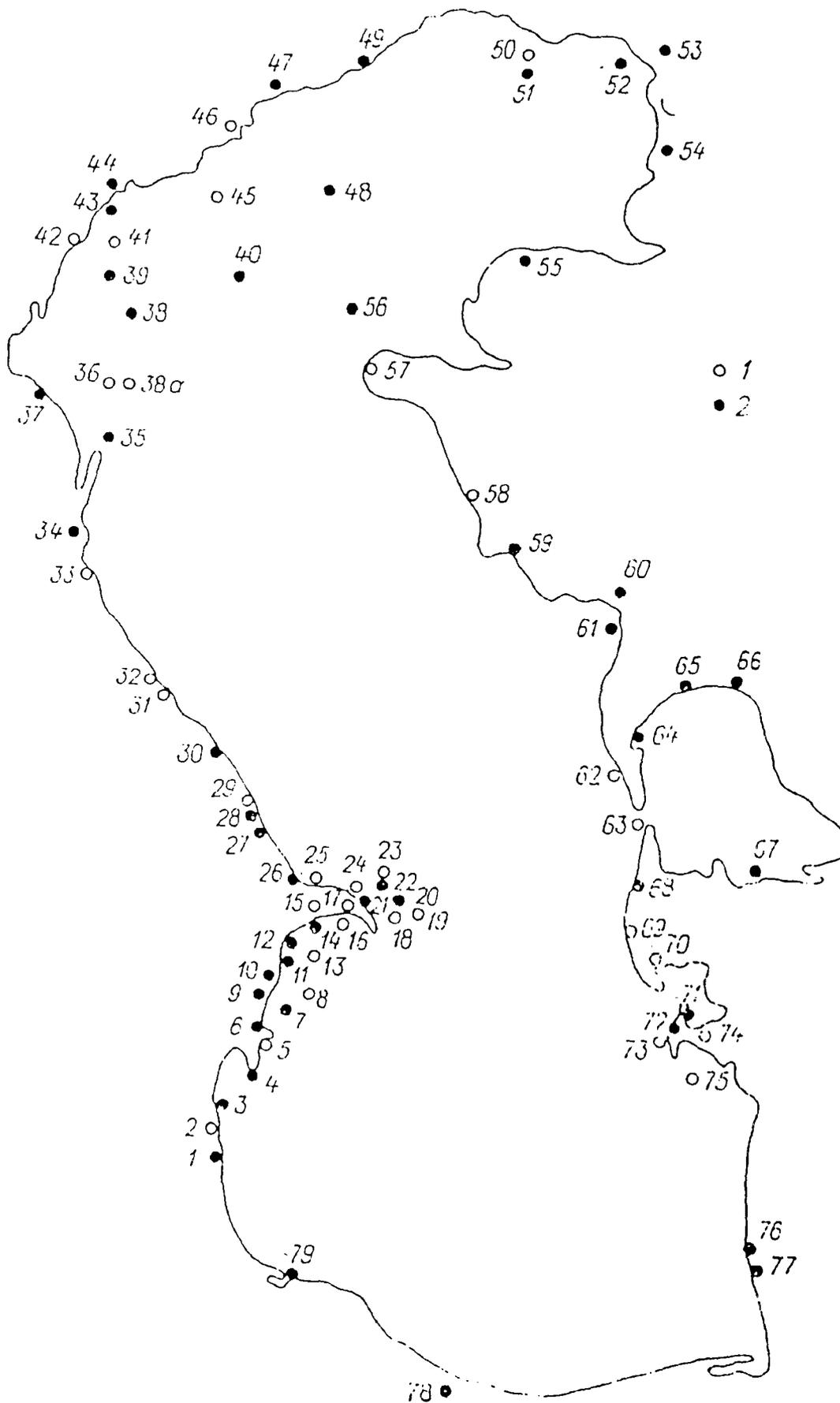
Picture 1.



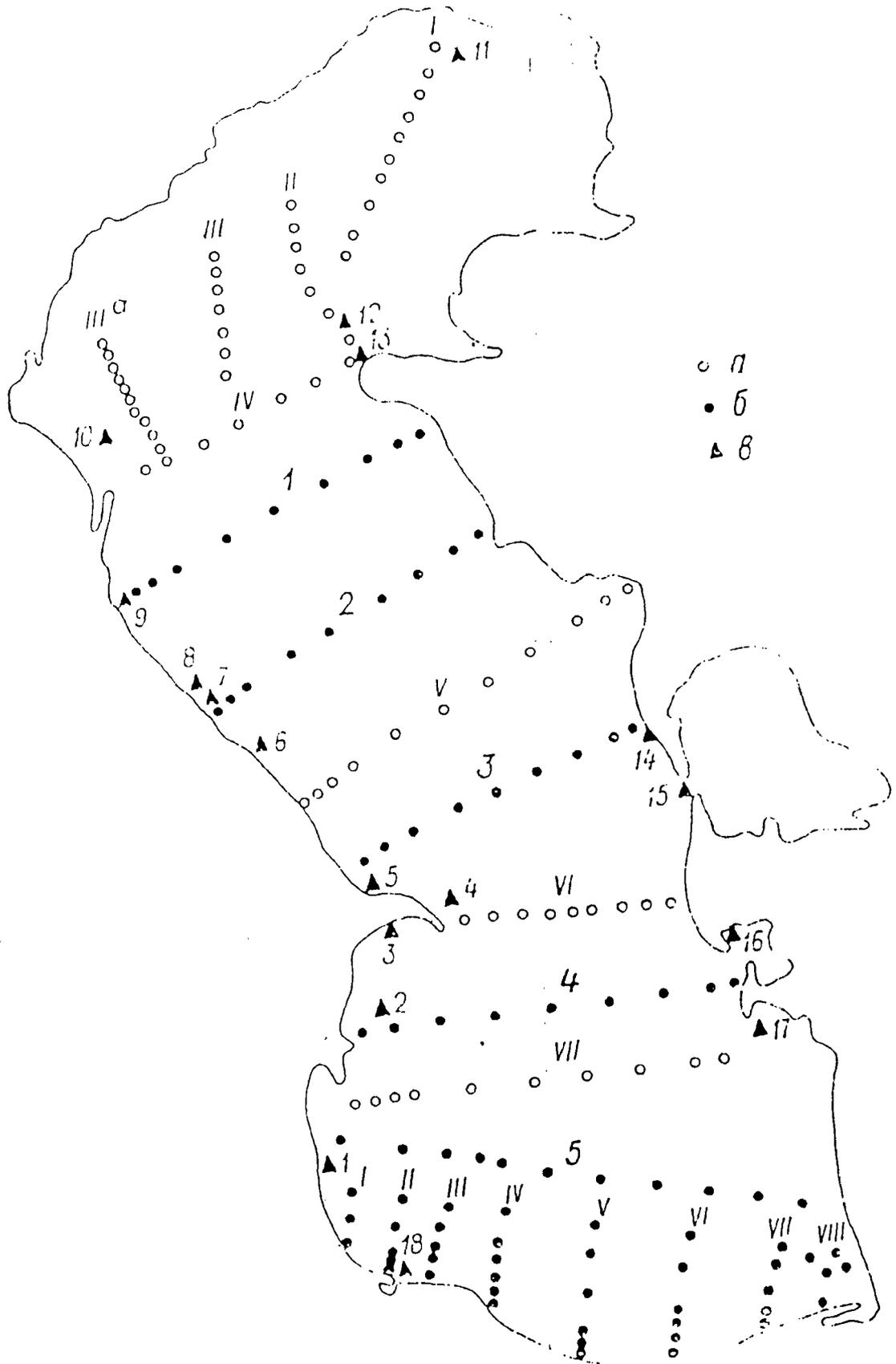
Picture 2.



Picture 3.  
The scheme of location of the coastal observation points  
in the Caspian sea (1991)  
1) operational 2) closed



Picture 4.  
The scheme of location of oceanographic stations  
on "secular" and standard sections and in roadstead points



"PALEOHYDROLOGY, PALEOCLIMATOLOGY AND PALEOENVIRONMENTAL  
RECONSTRUCTION OF THE CASPIAN SEA  
DURING THE LAST TENS OF THOUSAND YEARS:  
A CLUE FOR UNDERSTANDING CAUSES AND MECHANISMS OF ITS PRESENT-DAY  
WATER-LEVEL FLUCTUATIONS"

*F. Gasse, French coordinator of the program*

*contribution of F. Chalié*

*& of French participants : G. Blanc , M.-M. Blanc-Valleron , N. Clauer , A. Desprairies ,  
A. Foucault , P. Gautret-Maire , P.J. Giannesini , E. Gibert , F. Guichard , F. Mélières,  
F. Orszag , M. Steinberg , N. Tribovillard , D. Badaut-Trauth , P. Tucholka & G.M. Zuppi.*

## **I - GENERAL AIMS**

Prediction of future environmental conditions requires the understanding of causes and mechanisms of (i) the natural variability, induced primarily by climate fluctuations, and (ii) the human-induced changes.

It is now well-known that most lacustrine systems have been submitted to great fluctuations in their past water level stand. This has clearly been demonstrated in the Caspian sea catchment : on the Western coast of the Caspian sea (region of Mackachkala), sediment marine terraces, that are at present-day emerged give evidence of numerous past periods of high water level. For several of them, the carbonated shells that they contain have been dated through  $^{14}\text{C}$  and U/Th analyses. Shells from a terrace located at + 2,5 m above the present-day sea level exhibit a  $^{14}\text{C}$  age of  $245 \pm 70$  years B.P. (Fontes *et al.*, unpublished data). The terrace at about + 4 m above the present level is  $^{14}\text{C}$  dated at about 23,000 years B.P. (Fontes *et al.* , unpublished data). These high marine terraces evidence water-level fluctuations of great amplitude at different timescales of investigation : through the last few hundreds years, as well as through the last thousands years.

One valuable approach to progress in the understanding of causes and mechanisms of the present-day short-term fluctuations is the **detailed study** of these **past variations**.

We aim to reconstruct the environmental changes through the last tens of thousand years and to foccuss on understanding of causes and mechanisms involved in the water-level fluctuations for such **long record periods**. This has to be investigated in the frame of a modeling approach, integrating the different terms of the water budget. It requires that we consider both (i) the **present-day functioning** of the Caspian sea system, in order to interpret (ii) the **past changes**, as they are registered in deposited sediments.

## **II - MATERIAL**

The material nowadays available originates from several French-Russian and Russian sampling fields and from a French-Russian sea cruise (August 1994; fig. 1).

To address the two objectives defined above, we performed multidisciplinary studies and analyses on : 1 - *sea and continental waters*;  
2 - *sediments at the corresponding hydrological stations*.

### **III - SEA AND CONTINENTAL WATERS**

The analyses performed on waters concern, both the stable and radioactive isotopes and the hydrochemistry (trace elements, rare earth elements, heavy metals, ... ). Material comes from several preliminary fieldtrips (V.I. Ferronsky, 1991; J.-C. Fontes and P. Tucholka, 1992; F. Gasse and P. Tucholka, 1994) for waters from the region of Mackachkala and from the sea cruise for samples along a depth profile for the so-called "hydrological stations" (fig. 1). Studies on modern waters includes a large set of different complementary analyses, widely diversified.

#### **1 - Isotopes**

Isotopes data bring essential contribution for the understanding of the Caspian Sea water balance. It represents a powerful tool to approach the evaporation rate feature of the present-day system, including the waters dynamics, melting and movements. Most isotopic analyses have been conducted in close collaboration with the International Atomic Energy Agency IAEA (Vienna).

##### **1.a . Radioactive isotope: tritium.**

*Tritium* analysis, integrated in the Caspian sea program, were performed at the International Atomic Energy Agency (Vienna), (unpublished data). Tritium content of a water sample gives estimate of its age, since it inputs in the sea water cycle. The tritium analyses, recorded for depth profiles from six hydrological stations distributed on a North to South transect in the Caspian Sea, therefore evidence the water dynamics and mixing. It enables in particular to investigate the water exchanges *versus* depth, as well as the exchanges between the two topographic sub-basins : the middle basin and the Southern basin, according to the gradient from North (from where main inputs originate) to South. Tritium content feature (fig. 2) clearly establishes a significant distinction between the pattern of the middle basin and the Southern basin. Both basin have the same original waters, as mainly fed by the Volga rivers waters (80 % of the total inputs). All sites from South to North exhibit the same surface tritium content. In the Southern basin, the 200 to 500 m depth zone shows a mixing pattern, as far as the tritium content there regularly decreases. The deepest waters record a non-negligible tritium content, indicating a relatively young water age : this suggests a low turnover.

##### **1.b - Stable isotopes.**

*Oxygene-18 and deuterium* analyses (Clauer *et al.*, 1995 and IAEA, unpublished data) for the same depth-profile water samples emphasize the evaporation effect of the Caspian Sea, since all sea waters emphasize value positioned below the Meteorological World Line (WML) on the Oxygene-18 - Deuterium diagram (fig. 3). A careful check of hydrothermal waters content, versus river waters and other sea waters contents, enables to recognize thermally-induced interactions with the host-rocks. Finally, scatter of the values evidences an incomplete mixing of the different water supplies (Clauer *et al.*, 1995).

## 2 - Hydrochemistry

The Content in **heavy metals** is generally above that of the open oceanic water, whereas **Sr isotopic ratio** is slightly below. This significant behaviour difference between metals content and the Sr and Pb isotopic ratios suggest that complex mixing did not occurred (fig.4). (Clauer *et al.*, 1995).

**Rare Earth Elements** (La, Ce, Pr, Sm, Eu, Dy, Yb) distribution pattern is close to that of the open sea water, with a variable negative Ce anomaly (Clauer *et al.*, 1995).

## IV - SEDIMENTS.

These mainly come from the french-russian sea cruise of August 1994. Up to now, the only core SR01-GS9405 (fig. 1) were opened and sampled.

### 1 . *Paleoenvironmental and paleoclimatic proxy-data.*

Our studies mainly focussed on "classical" analyses for sediment samples each 10 cm depth interval : mineralogy, major chemical elements contents, biological remains (diatoms, pollen, ...).

Among environmental and climatic proxy data, several evidence two fairly well-discriminable sediment phases. A clear shift indeed appears at 90 cm depth in the chemical content elements, the carbonates, the Total Organic Content and the sulfur content records.

In addition to these sensitive **long-term fluctuations**, some other indicators suggest **shorter terms fluctuations**, at a timescale that may be comparable to the present-day water level fluctuations.

The sediment material is finely laminated, with alternance of grey and dark millimetric layers. A spectral analysis on the grey level intensity, provisionally performed versus a depth scale, suggests changes that may show a roughly cyclic pattern. They must however be re-interpreted *versus* a time scale, as soon as an uncertained chronological framework will be established.

The palaeomagnetic record (fig. 5) emphasizes both the 90 cm depth shift and corresponding long-term change, but also short-term cyclic variations.

Addressing the understanding of the modern water-level fluctuations, requires that further investigations foccuses on these short-term (roughly cyclic?) sedimentary changes.

### 2 - *Chronological framework.*

The chronological framework has to be established as accurately as possible to **address these short terms past variations** and to evaluate **timing and duration** of any environmental event recorded in fossil sediments.

For the sediment sequence SR01-GS9405 , four  $^{14}\text{C}$  dates by AMS (Accelerator Mass Spectrometry, Tandétron, Gif-sur-Yvette), were performed on the fine sediment fraction  $< 10\mu\text{m}$ . The 10cm depth level indicates a  $^{14}\text{C}$  age of ca. 6 kyrs B.P., plausible, since water content and biological remains both suggest that the modern water-sediment interface would not be recorded in this SR01-GS9405 sequence. Three other  $^{14}\text{C}$  dates all indicate the same value of about 20-22 kyr B.P., along 7 m depth and suggest that the fine fraction would not be all allochthonous: it contains a significant part of detritic carbonates, supposed to have input in the Caspian waters a non-negligible contribution of dead carbone. The values of ca 20 to 22 kyr B.P. are thus

assumed to be over-estimated. X-ray analyses of bulk sediment (in progress), should enable the determination of the proportions of authigenic and detritic carbonates and, therefore, the ages correction from contribution of dead carbone inputs, finally enabling recalculation of  $^{14}\text{C}$  activity values, if no input of dead carbone has occurred *via* detritical arrivals.

#### ***V - ABOUT NECESSARY FURTHER INVESTIGATIONS ...***

Our study, that practically started last year (end of year 1994), is currently in progress. The analyses on the first core in the Southern basin are to be finalised. Preliminary results achieved up to now, emphasizes need for further studies and sampling material. Supplementary sampling should be scheduled towards two main objectives. First, priority should be given to the ***water sampling of the Volga river***, the present-day main freshwater input to the Caspian Sea. This should be done at least, at a monthly time interval or twice a month, to investigate intra-annual variations of the water input rivers. This is a prerequisite to accurately understand the evaporation feature and hydrological system of the Caspian Sea. Sedimentary sequence, as well as hydrological depth profiles are up to now, quite sparse: ***further sediment collection*** should provide a more geographically exhaustive response to the past hydrological and climatic changes and precise preliminary results achieved for the sites investigated up to now.

#### ***REFERENCE***

Clauer N., Zuppi G.M., Toulkeridis, Stille P., Blanc G., Gasse F. & Ferronsky V.I. (1995) . Origin and evolution of Caspian Sea waters and solutes based on chemical and isotopic data. *Abstracts of the European Union of Geosciences*, Strasbourg, 9-13 april 1995.

**Acknowledgements:** This program is supported by the French Centre National de la Recherche Scientifique (CNRS-INSU). It is developped in the frame of a close collaboration with the International Atomic Energy Agency (Vienna), and with the Russian Academy of Sciences (Moscow, Russia). Several french research units are involved in the Caspian Sea program: URA 723 CNRS (Orsay), the Centre de Géochimie de la Surface (Strasbourg) and the Centre des Faibles Radioactivités (Gif-sur-Yvette).



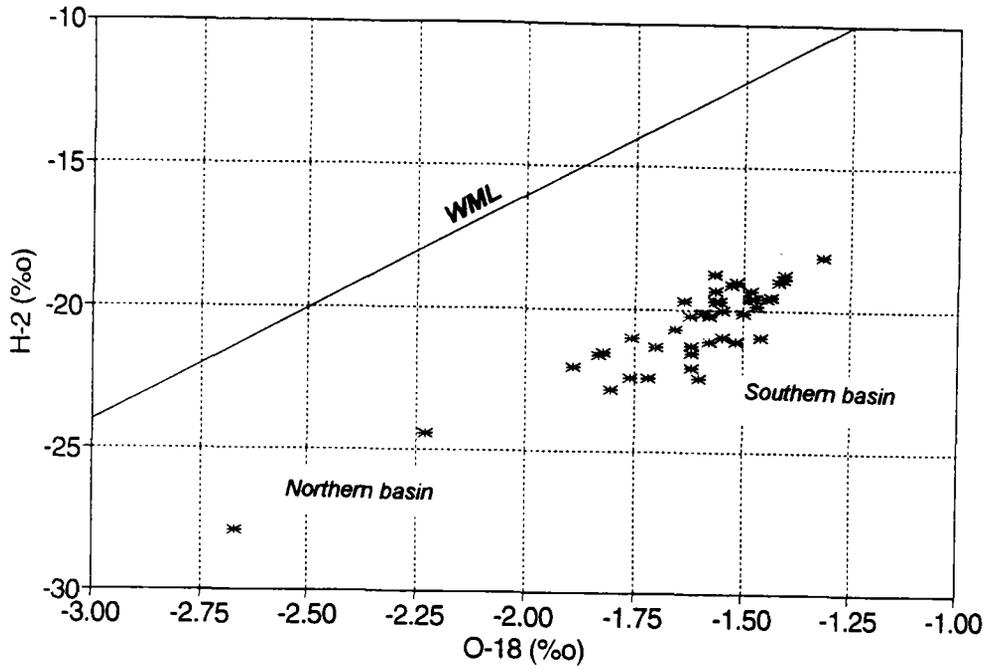


Fig. 3 - Oxygen-18 - Deuterium diagram for water samples of Caspian Sea.  
 (After Clauer *et al.*, 1995 and IAEA, unpublished data).

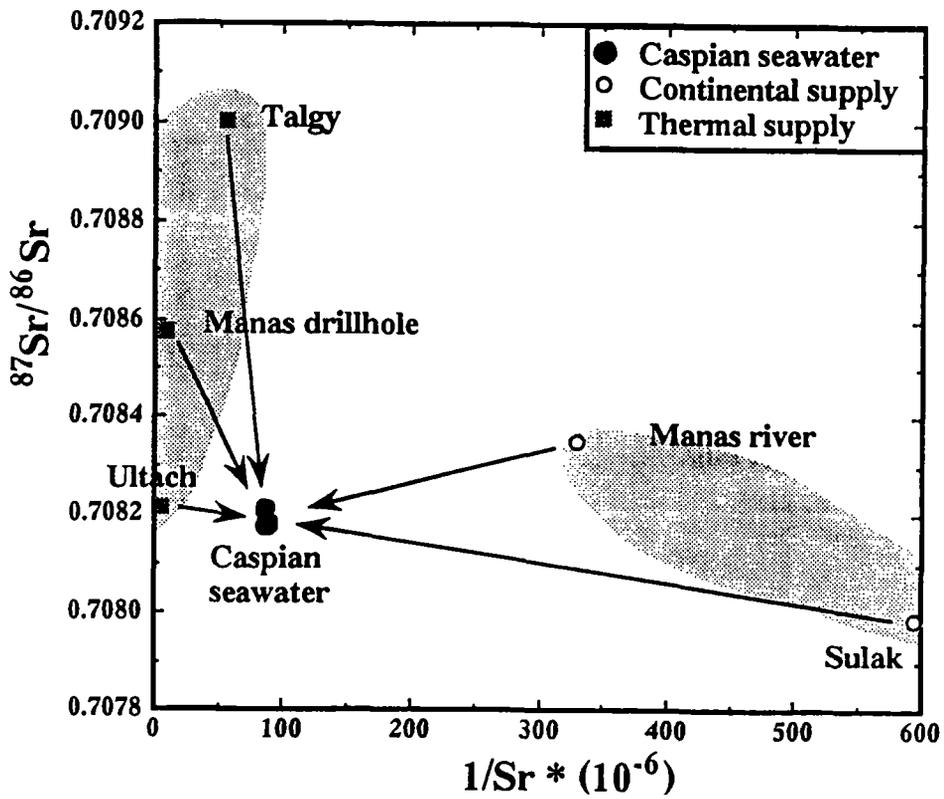


Fig. 4 - Variations of the Sr ratio in modern waters from the region of Makachkala: Caspian Sea waters, rivers waters and thermal supplies.

(After Clauer *et al.*, 1995).

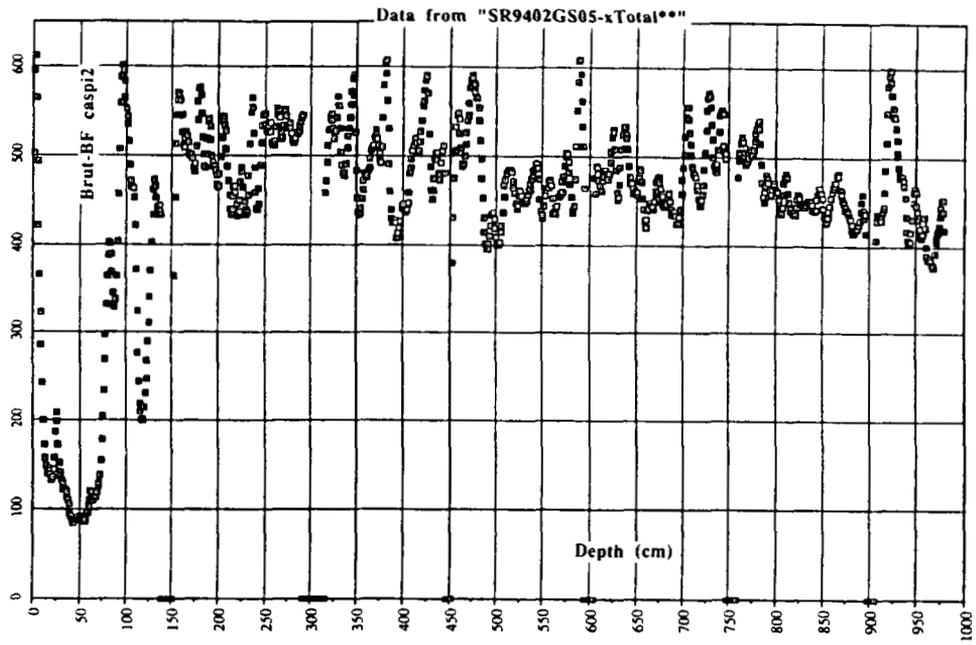


Fig. 5 - Palaeomagnetic record in the SR01-GS9405 sequence (site 2, see fig. 1)

(After Guichard *et al.*, unpublished)

## SOME TRITIUM AND STABLE ISOTOPE MEASUREMENTS OF WATER SAMPLES FROM THE CASPIAN SEA

K. Froehlich & K. Rozanski  
IAEA, Vienna, Austria

The IAEA recently received 41 samples of water taken from the Caspian Sea during the Russian-French cruise in August 1994. The samples were collected at seven locations (Fig.1). At two of these locations (No. 10 in the Central Basin; No. 1 in the Southern Basin) the water column was sampled at several depths, from the surface down to 770 m and 847 m, respectively. The water samples were analysed in the IAEA Isotope Hydrology Laboratory with respect to tritium, oxygen-18, deuterium and conductivity. The measuring results and their preliminary interpretation are described below.

### Tritium

There is a distinct difference in the vertical distribution of tritium in the Central and the Southern Basin. In the Central Basin, the tritium content below a well-mixed layer, which is at about 100 m, is fairly homogenous and centres at about 14 TU. In the Southern Basin, however, a distinct stratification was found: the tritium content decreases gradually from ca. 14 TU at 100 m to around 9 TU at 500 m. Below 500 m the tritium content was found to be constant at about 9 TU. The lower tritium values of the Southern Basin point to a different mixing pattern and generally higher apparent age of the water in this basin. More detailed information on the water circulation and mixing in the Caspian Sea would be possible through additional He-3 measurements (use of the H-3/He-3 technique).

### Stable isotopes

The water samples appeared to be substantially enriched in both deuterium and oxygen-18. The river run-off into the Caspian Sea is known to have an oxygen-18 value of about -10‰, and the most enriched values in the Central and Southern Basin were found at around -1.5‰. Obviously, most of the enrichment takes place in the shallow Northern Basin, as indicated by the locations 13 and 12 with oxygen values of -2.76‰ and -2.23‰, respectively.

The most interesting aspect of the stable isotope data so far available, is the apparent enrichment in the heavy isotopes of the main water body (Central and Southern Basin) with respect to surface water. Although rather small (about 0.2‰), this difference appears to be significant and thus suggests that the water at depth is from the previous low-level state of the Caspian Sea (1950 -1977). Assuming that the sea reached hydrological and isotopic steady state during this time period, with the average oxygen-18 enrichment of 8.5‰, one can calculate an average relative humidity over the sea of 65%. If the relative humidity did not significantly change for the last 20 years, the observed isotopic depletion of the surface layer by 0.2‰ could be interpreted in terms of an increase of the ratio of the total inflow rate and the evaporation rate by about 10%.

Conclusion

The results of this reconnaissance of the work to be done within the framework of an isotope-based study of the Caspian Sea appeared to be encouraging. Tritium showed potential in addressing the dynamics of circulation and mixing processes in (and between) the Central Basin and the Southern Basin. Aspects of the water balance, such as change in the inflow-evaporation ratio and horizontal and vertical exchange of water masses can also be studied through the involvement of the stable isotopes oxygen-18 and deuterium.

Further, detailed isotope-based studies require a more comprehensive sampling of the Caspian Sea. A section of sampling locations from north to south and at sections from west to east in all three parts of the sea (northern shallow one, Central and Southern Basin) should repeatedly be sampled during cruises, whereby especially in the Central and Southern Basin the sampling (and oceanographic measurement) of depth profiles would be crucial. Preliminary measurements of the conductivity, which are not reported in this abstract, have also shown the need for complementary measurements of chemical and oceanographic parameters.

Acknowledgement

We thank our French and Russian colleagues involved in the joint French-Russian cruise in August 1994 for the provision of the samples.

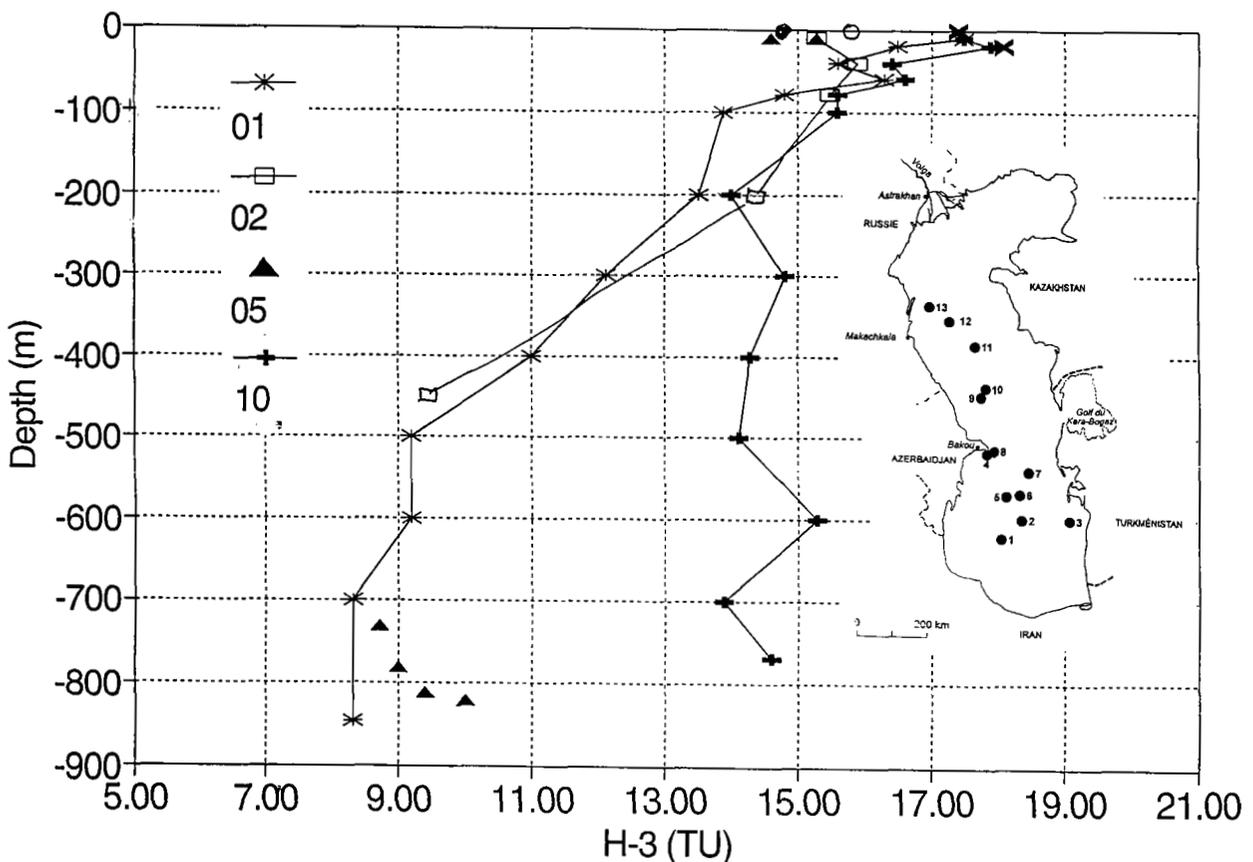


Fig.1: Tritium of samples taken in August 1994. Inset: Sampling locations.

No.	Title	Languages	No.	Title	Languages	No.	Title	Languages
52	SCOR-IOC-UNESCO Symposium on Vertical Motion in the Equatorial Upper Ocean and its Effects upon Living Resources and the Atmosphere; Paris, 6-10 May 1985.	E	74	IOC-UNEP Review Meeting on Oceanographic Processes of Transport and Distribution of Pollutants in the Sea; Zagreb, Yugoslavia, 15-18 May 1989.	E	96	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; Zanzibar, United Republic of Tanzania, 17-21 January 1994.	E
53	IOC Workshop on the Biological Effects of Pollutants; Oslo, 11-29 August 1986.	E	75	IOC-SCOR Workshop on Global Ocean Ecosystem Dynamics; Solomons, Maryland, USA, 29 April-2 May 1991.	E	96	IOC-UNEP-WMO-SAREC Suppl 1 Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; Submitted Papers	E
54	Workshop on Sea-Level Measurements in Hostile Conditions; Bidston, UK, 26-31 March 1988	E	76	IOC-SCOR Workshop on Causes and Consequences of Sea-Level Changes on the Western Indian Ocean Coasts and Islands; Mombasa, Kenya, 24-28 June 1991.	E	96	IOC-UNEP-WMO-SAREC Suppl 2 Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; Submitted Papers	E
55	IBCCA Workshop on Data Sources and Compilation, Boulder, Colorado, 18-19 July 1988.	E	77	IOC-CEC-ICES-WMO-ICSU Ocean Climate Data Workshop Goddard Space Flight Center; Greenbelt, Maryland, USA, 18-21 February 1992.	E	96	2. Sea Level; Zanzibar, United Republic of Tanzania 17-21 January 1994.	E
56	IOC-FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP); Cleveland, Australia, 24-30 July 1988.	E	78	IOC-SCOR Workshop on Programme Development for Harmful Algal Blooms; Newport, USA, 2-3 November 1991.	E	97	IOC Workshop on Small Island Oceanography in Relation to Sustainable Economic Development and Coastal Area Management of Small Island Development States; Fort-de-France, Martinique, 8-10 November, 1993.	E
57	IOC Workshop on International Co-operation in the Study of Red Tides and Ocean Blooms; Takematsu, Japan, 16-17 November 1987.	E	79	IOC-SCOR Workshop on River Inputs of Nutrients to the Marine Environment in the WESTPAC Region; Penang, Malaysia, 26-29 November 1991.	E	98	ColMSBlack '92A Physical and Chemical Inter-calibration Workshop; Erdemli, Turkey, 15-29 January 1993.	E
58	International Workshop on the Technical Aspects of the Tsunami Warning System; Novosibirsk, USSR, 4-5 August 1989.	E	80	IOC-SCOR Workshop on Development for Harmful Algal Blooms; Newport, USA, 2-3 November 1991.	E	99	IOC-SAREC Field Study Exercise on Nutrients in Tropical Marine Waters; Mombasa, Kenya, 5-15 April 1994.	E
58 Suppl.	Second International Workshop on the Technical Aspects of Tsunami Warning Systems, Tsunami Analysis, Preparedness, Observation and Instrumentation. Submitted Papers; Novosibirsk, USSR, 4-5 August 1989.	E	81	Joint IAPSO-IOC Workshop on Sea Level Measurements and Quality Control; Paris, 12-13 October 1992.	E	100	IOC-SCA-NOAA Regional Workshop for Member States of the Western Pacific - GODAR-II (Global Oceanographic Data Archeology and Rescue Project); Tianjin, China, 8-11 March 1994.	E
59	IOC-UNEP Regional Workshop to Review Priorities for Marine Pollution Monitoring Research, Control and Abatement in the Wider Caribbean; San José, Costa Rica, 24-30 August 1989.	E, F, S	82	BORDOMER 92: International Convention on Rational Use of Coastal Zones. A Preparatory Meeting for the Organization of an International Conference on Coastal Change; Bordeaux, France, 30 September-2 October 1992.	E	101	IOC Regional Science Planning Workshop on Harmful Algal Blooms; Montevideo, Uruguay, 15-17 June 1994.	E
60	IOC Workshop to Define IOCARIBE-TRODERP proposals; Caracas, Venezuela, 12-16 September 1989.	E	83	IOC Workshop on Donor Collaboration in the Development of Marine Scientific Research Capabilities in the Western Indian Ocean Region; Brussels, Belgium, 12-13 October 1992.	E	102	First IOC Workshop on Coastal Ocean Advanced Science and Technology Study (COASTS); Liège, Belgium, 5-8 May 1994.	E
61	Second IOC Workshop on the Biological Effects of Pollutants; Bermuda, 10 September-2 October 1988.	E	84	IOC Workshop on Coastal Oceanography in Relation to Integrated Coastal Zone Management; Kona, Hawaii, 1-5 June 1992.	E	103	IOC Workshop on GIS Applications in the Coastal Zone Management of Small Island Developing States; Barbados, 20-22 April 1994.	E
62	Second Workshop of Participants in the Joint FAO-IOC-WHO-IAEA-UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region; Accra, Ghana, 13-17 June 1988.	E	85	International Workshop on the Black Sea; Varna, Bulgaria 30 September - 4 October 1991.	E	104	Workshop on Integrated Coastal Management; Dartmouth, Canada, 19-20 September 1994.	E
63	IOC/WESTPAC Workshop on Co-operative Study of the Continental Shelf Circulation in the Western Pacific; Bangkok, Thailand, 31 October-3 November 1989.	E	86	Taller de trabajo sobre efectos biológicos del fenómeno «El Niño» en ecosistemas costeros del Pacífico Sudeste; Santa Cruz, Galápagos, Ecuador, 5-14 de octubre de 1989.	S only (Summary in E, F, S)	105	BORDOMER 95: Conference on Coastal Change; Bordeaux, France, 6-10 February 1995.	E
64	Second IOC-FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP); Phuket, Thailand, 25-31 September 1989.	E	87	IOC-CEC-ICES-UNEP Regional Workshop for Member States of Eastern and Northern Europe (GODAR Project); Odintsk, Russia, 17-20 May 1993.	E	106	IOC/WESTPAC Workshop on the Paleographic Map; Bali, Indonesia, 20-21 October 1994.	E
65	Second IOC Workshop on Sardine/Anchovy Recruitment Project (SARP) in the Southwest Atlantic; Montevideo, Uruguay, 21-23 August 1988.	E	88	IOC-SCOR Workshop on Ocean Sciences in Non-Living Resources; Perpignan, France, 15-20 October 1990.	E	107	IOC-ICBU-NIO-NOAA Regional Workshop for Member States of the Indian Ocean - GODAR-III; Dona Paula, Goa, India, 6-9 December 1994.	E
66	IOC ad hoc Expert Consultation on Sardine/Anchovy Recruitment Programme; La Jolla, California, USA, 1989.	E	89	IOC Seminar on Integrated Coastal Management; New Orleans, USA, 17-18 July 1993.	E	108	UNESCO-IHP-IOC-IAEA Workshop on Sea-Level Rise and the Multidisciplinary Studies of Environmental Processes in the Caspian Sea Region; Paris, 9-12 May 1995.	E
67	Interdisciplinary Seminar on Research Problems in the IOCARIBE Region; Caracas, Venezuela, 28 November-1 December 1989.	E (out of stock)	90	Hydroblack'91 CTD Inter-calibration Workshop; Woods Hole, USA, 1-10 December 1991.	E	108 Suppl.	Workshop on Sea-Level Rise and the Multidisciplinary Studies of Environmental Processes in the Caspian Sea Region; Submitted Papers; Paris, 9-12 May 1995.	E
68	International Workshop on Marine Acoustics; Beijing, China, 26-30 March 1990.	E	91	Réunion de travail IOCEA-OSNLR sur le Projet « Budgets sédimentaires le long de la côte occidentale d'Afrique » Abidjan, Côte d'Ivoire, 26-28 juin 1991.	F			
69	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica; Leningrad, USSR, 28-31 May 1990.	E	92	IOC-UNEP Workshop on Impacts of Sea-Level Rise due to Global Warming. Dhaka, Bangladesh, 16-19 November 1992.	E			
69 Suppl.	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica; Submitted Papers; Leningrad, USSR, 28-31 May 1990.	E	93	BMT-IOC-POLARIMAR International Workshop on Training Requirements in the Field of Eutrophication in Semi-Enclosed Seas and Harmful Algal Blooms; Bremerhaven, Germany, 29 September - 3 October 1992.	E			
70	IOC-SAREC-UNEP-FAO-IAEA-WHO Workshop on Regional Aspects of Marine Pollution; Mauritius, 29 October - 9 November 1980.	E	94	SAREC-IOC Workshop on Donor Collaboration in the Development of Marine Scientific Research Capabilities in the Western Indian Ocean Region; Brussels, Belgium, 23-25 November 1993.	E			
71	IOC-FAO Workshop on the Identification of Penaeid Prawn Larvae and Postlarvae; Cleveland, Australia, 23-28 September 1990.	E						
72	IOC/WESTPAC Scientific Steering Group Meeting on Co-Operative Study of the Continental Shelf Circulation in the Western Pacific; Kuala Lumpur; Malaysia, 9-11 October 1990.	E						
73	Expert Consultation for the IOC Programme on Coastal Ocean Advanced Science and Technology Study; Liège, Belgium, 11-13 May 1991.	E						