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Obserwacje nad przeformowaniem się brzegów zbiornika w Goczałkowicach — Observations on the transformation of banks in the Goczałkowice Reservoir

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The process of transformation of banks in dam reservoirs is a complex phenomenon of great importance for many of their properties. As a result of this process not only a deformation of the banks of the reservoir takes place, but also a more intensive accumulation of sediments, changes in the morphology of the bottom and of some physico-chemical properties of the water.

During the last twenty years a series of publications concerning this problem have appeared. K a č u g i n (1961) stresses the necessity of observation of this process, being of the opinion that only on the basis of investigations from all possible angles can the destruction of banks in newly constructed reservoirs be correctly foreseen by means of the method of analogy.

In Poland no investigations of this kind have yet been conducted on a larger scale. S k i b n i e w s k i (1956), in his work on the importance of scrub on banks in river and reservoir economy, mentions in a general manner the process of washing out of banks.

The present observations on the transformation of banks in the Goczałkowice reservoir, conducted in the years 1958—1962, are a continuation of preliminary observations carried out in 1957 by M a z u r (1958). Their aim was to characterize the process of transformation of the banks during the first years after the flooding of the reservoir. To render possible a comparison of results in presenting the degree of destruction of banks in the course of time, the photographic method was mostly used, as in the observations of M a z u r. Engineering and geological measurements were carried out as an additional aid. Z u b e n k o (1961) proposes the use of aerial photography for investigations of this kind, concerning large dam reservoirs.

A transformation of the banks of a reservoir mainly takes place as a result of their washing out or subsidence. Its character and dimensions

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depend on a series of factors, of which the most important are: parameters of water waves in the reservoir, fluctuations of water level, kind of rock and of soil forming the embankment and the manner of their stratification, height and morphology of banks, their character and the displacement of sediments along the banks.

Morphological, hydrological, and climatic data

The Goczałkowice reservoir was formed by means of an earthern dam, 3 km. long, built across the broad, shallow, and flat-bottomed valley of the Upper Wisła (Vistula) slightly above the locality of Goczałkowice The valley here is unilaterally developed; the northern slopes, higher and steeper, are formed by the undulating plateau (watershed) of Rybnik — Pszczyna (260-280 m. above sea level); the southern ones are lower, nearly flat with an incline of 0,5 pro mille and form the western part of the Oświęcim Depression. From here onwards the northern left bank of the reservoir, relatively gentle in its upper part (Fig. 4) becomes in some places, from the locality Wisła Wielka towards the dam, rather high and steep (Fig. 5). The southern right bank, however, in the sector from the dam to the place where the river Bajerka falls into the reservoir, is entirely flat (Fig. 6), on the average 256-258 m. above sea level. The remainder of the bank, from the Bajerka to the dikes enclosing the reservoir on its upper side, is formed by an artificial check dike, 10 km. long, built during the construction of the dam to safeguard low-lying inhabited terrains (255-256 m. above sea level). The greater part of this dike, built of earthern material liable to be easily washed out, has recently been reinforced against further damage by concrete slabs (Fig. 7). The shape and situation of the reservoir as well as the morphology of its bottom is illustrated on the map (Fig. 1). The average transversal decline of the valley is variable and fluctuates between 1-4 pro mille, and the average longitudinal (consequent) decline amounts to 0,5-0,8 pro mille (W i n t e r 1953). The old bed of the Wisła river, cut out of the bottom of the reservoir, passes lengthwise through it, complete with its protective dikes, conserved as a whole but broken in places, which rise, in the upper part of the reservoir above the water level. The maximum exploitable surface of the reservoir (when filled up to the ordinate 256 m. above sea level) is about 30 km.^{2}, its length amounting to nearly 13 km. The breadth of the reservoir varies from 2-5 km. When the content of the reservoir is at its minimum, up to the ordinate of 250,5 m. above sea level, it is 10,3 km^2. The depth of the reservoir, as in all dam reservoirs, diminishes in the direction from the dam towards the upper part of the reservoir. It must be noted, moreover, that owing to the primitive formation of the bottom of the valley the deepest parts of the reservoir lie near the left northern

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Fig. 1. Goczałkowice reservoir

bank, and the shallowest less than 2 m. in its south-eastern part. The depth of the reservoir when maximally filled near the sluices in the bed of the Wisła river is about 12 m., and near the bed 7-8 m.

The Goczałkowice reservoir is characterized by a slow intake and a slow outflow of water. It is mostly destined for water supply. Its retentive role, consisting in a strong draining into the reservoir of waters from the rise during spring thaws and in summer and the detention of flood-water, is a secondary one. In consequence, fluctuations in the water level of the reservoir are relatively small. Fig. 2 presents the rise in the

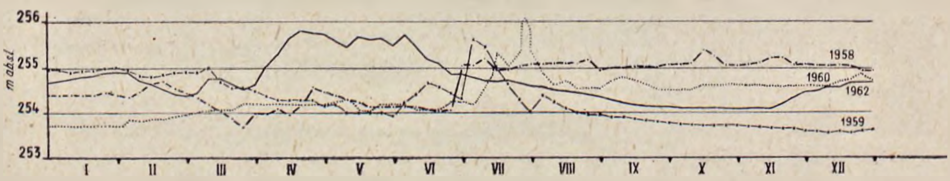

Fig. 2. Water level in the reservoir in the years 1958-1962

level of water in the reservoir during the years when observations were carried out. It shows that more considerable fluctuations of the water level in the reservoir (except in 1962, when this period occurred earlier) usually take place in July, a period of torrential rains in the basin of the Upper Wisła. The mean figure for rainfall during this month, calculated for a considerable number of years, amounts to 142 mm for Skoczów and is the highest in the year (S t a r m a c h 1957).

The wave-motion of water in the reservoir, one of the main factors of washing out of the banks, depends not only on its depth and breadth but also on the velocity of the wind and its duration. During the years of my investigations the character of the winds, noted by a meteorological station of the Laboratory for Water Biology of the Polish Academy of Sciences situated in the neighbourhood, in Ochaby, was determined by the 3 wind roses on Fig. 3. On the axes of the rose for every year the principal directions and the so-called semidirections of the winds are marked. On each axis of direction the yearly sum of frequency of the winds is given. Beneath, the annual mean figures for their velocity and the number of calms in percentage of the sum of all directions are noted. As can be seen from these data, winds blow most frequently from a south-westerly or southern direction. Thus, they mostly cross the lake transversally. Their mean annual velocity (in the years 1958-1962 2,2 m./sec. on the average) is higher than that given by W i ś n i e w s k i and P a c h n i k (1959) as the minimum limit of wind velocity (1-2 m./sec.) at which waves begin to form. The high percentage of noted calms (56 per cent) indicates that the mean figures for wind velocity in the period of wind might be higher. According to the authors mentioned above the maximum wind velocities

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over the Goczałkowice reservoir attain 20 m./sec. This reservoir is therefore exposed to a considerable wave-motion of water, mostly from the windward direction, SW and S, and in the spring period, when the velocity and frequency of winds are greater. The investigations of Wiśniewski and Pachnik showed that, in 1958, near the water

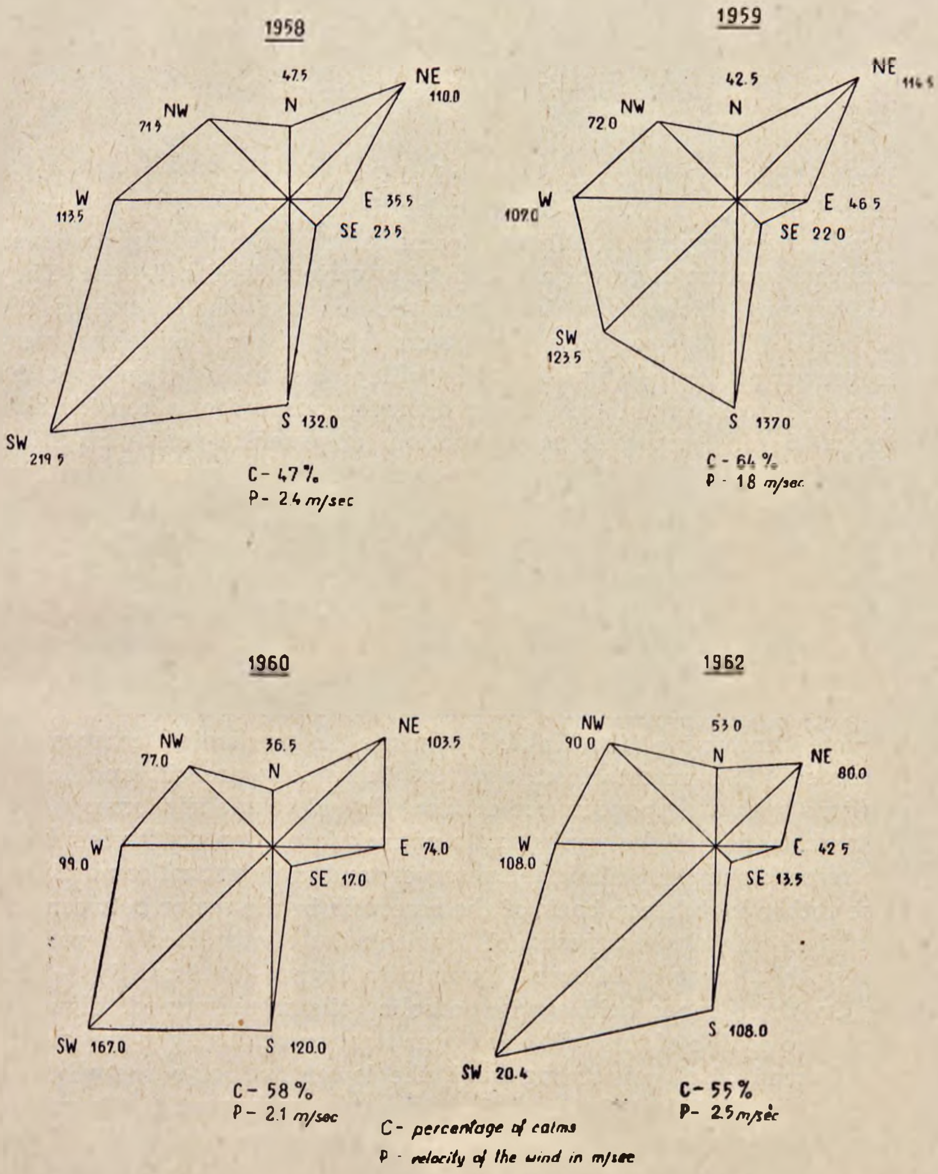

Fig. 3. Annual sum of the direction of winds, mean velocity and percentage of calms, according to the neighbouring meteorological station in Ochaby

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intake, waves 0,1 m. high formed 69 per cent of all measurements and waves higher than 0,1 m 31 per cent. The maximum height of waves noted in the reservoir is relatively very great, amounting as it does to 2,5 m. The frequency of the highest and very steep waves (relation of the length of the wave to its height), of considerable activity as to destruction of the banks, is not very great.

Geological structure of the soil

The bed of the reservoir is composed of Quarternary formations settled on eroded Tertiary Miocene strata. Under the entire cup of the reservoir and its borders, layers of Miocene loams, of the so-called fourth level, lined with a stratum of gravel, are situated at various depths (7-14 m.) They are of varying thickness which diminishes on the whole towards the right bank. The Quarternary formations lying above the loams, very heterogenous on the left border of the valley, pass in the vicinity of the right slope into layers of loess clays, homogeneous and of a considerable thickness (5 m.), composed at the bottom of greenish-yellow so-called sub-loess loams, and at the top of younger yellowish-brown formations resembling loesses.

On these upper formations resembling loesses, lacking of lime and containing some ferruginous concretes and mica, probably settled in a water milieu (early Diluvium), very acid (pH 4,0-5,5) silt and podsolic soils were formed. It is of these soils, therefore, that the natural right bank consists, in the sector from the dam to the mouth of the Bajerka. They form the substratum of a further sector of this bank, an artificially constructed protective dike. Table I presents the mechanical composition of these soils. As results from analyses these soils are silt and loamy formations with a preponderance of fine silt and coarse silt loam.

Differentiation of the upper strata of rock formation on the left bank of the reservoir appears along the reservoir and in a vertical composition.

The rather high, steep bank of the reservoir in the sector between the dam and the intake composed of fluvioglacial sands lined at various depths with a layer of Miocene loams of a higher level mostly 1-2 m. thick. On these sands acid sandy podsolic soils were formed. Figure 8 presents the profile of this soil. The upper stratum of this light-grey sandy soil is formed of clayey strong sand, the lower one, of a rusty brown colour, of argillaceous light sand. In the entire sandy part of the profile appear fragments of loam of various size, disposed irregularly. The layer of underlining greyish-blue loam is a heavy clay with a considerable content of silt and clay parts (51 per cent) and a higher content of sand than that of pure loams.

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Tab. I

Mechanical composition of embankment soils of the Goczałkowice reservoir in percentage

Bank of reservoir	Locality	No. of profile	Depth in cm	Particle diameter in mm						Soil textural group
				1-0.1	0,1-0,05	0,05-0,02	0,02-0,006	0,006-0,002	<0,002	
Left	Goczałkowice	1	0–120	66	7	11	8	3	5	heavy loamy sand
			120–160	73	7	8	2	0	10	light loamy sand
			160–200	12	3	4	19	24	38	heavy loam
	Łąka	2	0– 97	23	10	31	19	6	11	silt and loam soil
			97–200	6	7	33	25	7	22	silt and loam soil
	Łąka below the fishery port	4	0– 95	28	11	30	16	5	10	silt soil
			95–130	54	15	21	4	0	6	light loamy sand
	Łąka - Wisła Wielka	5	0–100	40	16	25	8	2	9	silt soil
			100–280	96	2	0	0	0	2	loose sand
	Wisła Wielka	7	0– 15	52	11	29	15	5	8	silt soil
	Wisła Mała	9	0– 20	24	12	30	[illegible]			silt soil
Right	Forest above the dam	10	0– 35	12	11	40	37			silt and loam soil
	Podjaz	11	0– 20	12	10	36	22	7	13	silt and loam soil
	Mouth of Bajerka river	12	0– 18	14	16	31	19	7	13	silt and loam soil
	Frelichów	15	0– 16	23	9	32	20	6	10	silt and loam soil
	Zabłocie	16	0– 25	18	16	32	34			silt soil (alluvial soil)

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The short, steep sector of the bank between the waterwork intake and the village Łąka is formed of very thick, light yellow loess formations (0-97 cm.) with a characteristic lower layer of greenish-yellow sub-loess loams lined with fluvioglacial sands. The profile of this bank is presented in Fig. 9. As results from analyses of the mechanical composition the upper stratum of the bank (arable podsolic soil) is a loamy silt soil formation with a slight addition of sand. The lower layer of the loams (< 97 cm.) is also a loamy silt soil formation, but with a much higher content of loamy parts and a smaller fraction of sand.

The sector of the embankment from the village of Łąka to the end of the reservoir is also composed of loess formations (arable podsolic soils containing sand) (profile 4 and 5) with a thickness of about 1 m. below Wielka Wisła and a greater one above. Underneath lie very thick greyish-yellow loose fluvioglacial sands with grains of various size or, as in the vicinity of Łąka, brown (morainic) light clayey and silt sands. The stratification and aspect of profile 5 is presented in Fig. 10. The amount of sand in the upper silt stratum of this soil is greater than in silt formations of aqueous origin on the right bank of the reservoir or in typical sub-Carpathian loesses. The upper terrains of the bottom of the valley which emerge periodically from the reservoir (profile 16) are mostly composed of old riverside alluvial silt soils covered with a minimal layer of reservoir sediments.

Transformation of reservoir banks

The factors discussed above, decisive for the transformation of the embankment, indicate that in view of the situation of the Goczałkowice reservoir on the line east-west, its left northern bank, between the dam and the village of Wisła Wielka, is the most exposed to washing out and subsidence. The first greater intensification of the destroying activity of waves on this side of the reservoir took place distinctly during the last three months of 1956 (Mazur 1958), a short time after the entire flooding of the reservoir.

In the sector from the dam to the intake the waves break against the rather high (2 m.), steep bank, washing out the poorly resistant, from this point of view, strata of sandy soil and leaving the lower loamy layer of the bank washed out in a lesser degree (Fig. 12). This being more resistant, owing to its high upper limit of plasticity (Chalfin 1954). This layer, when the sand carried by the reflected waves settles upon it, forms at present a vast sandy beach which limits the strength of the beating waves at normal water level in the reservoir. The indentification of this process in the years 1957-1962 is illustrated by Figs. 11, 12, and 13. The photographs show that the transposition of the line of the banks in this sector during

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these five years is considerable: it amounts to about 10 to 25 m. This is facilitated by a very unrestant and loose sand stratum and sources of ground-water flowing out of the bank which remain on the impermeable loams. The water saturates the soil of the bank to a maximum, thus increasing its fluidity and therefore its tendency to subsidence.

The region of water intake is reinforced by concrete slabs.

The destruction of the bank constructed of loess silt soil lined with sub-loess clays is no less intensive between the intake and the village of Łąka. This is shown in Fig. 14, 15, and 16 with a sight on a fixed point formed by a big oak trunk located on the bottom and Figs. 17, 18, and 19 which represent the situation near the house No. 227 in Łąka. It can be seen that in 1957 the line of the bank ran quite near the trunk and far away from the above-mentioned house, while in 1959 it shifted away from the trunk far into the embankment, up to the very wall of the house which the inhabitants had abandoned in the meantime. In 1962 the trunk was already at a distance of 25 m. from the bank and only rubble of the former house remained on the shore. It must be noted that in the region of the trunk the retreating of the bank, overgrown with trees and shrubs, is relatively smaller. In the nearest neighbourhood (Fig. 20) the reservoir cut much further, for about 35 m., into cultivated fields. This is an example of how shrubs and trees can reinforce this type of bank.

The high degree of transformation of the bank in this sector results from a considerable intensification of subsidence processes. The cause of this state of affairs must be sought in the physical and chemical properties of this kind of soil. When a higher water level of the reservoir causes a rise of the ground-water in the embankment, the silt material of the soil in the lower part of the profile (sub-loess clays), owing to its finely porous texture, becomes saturated with water up to its maximum absorberancy (gleyings are visible at 1,5-1,8 m. above the water level of the reservoir), thus increasing the fluidity of these strata and rendering their washing-out earlier. The saturated layers of sub-loess clay, owing to a considerable content of loamy parts (Table I) expend and afterwards, when the water in the reservoir falls and the pressure of its outflow is negative, they dry up and contract, causing cracks, disturbing the stability of the soil on the bank and thus increasing its subsidence.

Saturation of these soils with water is made easy owing to the layer of sand situated beneath them. A v a k i a n and Š a r a p o v (1962) present the scheme of a similar subsidence of banks with soils of this kind. The range of influence of the reservoir on the embankment can amount to 300-400 m. from the line of the bank (V l a d y č e n s k i 1958). The material of the subsiding soil is very rapidly washed by the waves.

The embankment in the sector 2 km. above the locality of Łąka was also subject to considerable transformations, caused not only by waves but mainly owing to an unfavourable disposition of the soil and its quality.

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In the lower part of the profile of the bank a layer of loose sand easily washed out by waves caused the thin superficial stratum of silt soil to subside. In the region of the fishery harbour this situation has altered lately, as the banks have been reinforced with stones against further washing out. The destruction of high banks on the terrain of the old sand-pit has also decreased, the large artificial flat shore formed by the exploitation of sand for building purposes checking the water waves (Fig. 21). Transformation of the banks in these places is principally caused by erosion resulting from water precipitation.

From this place onwards, up to the end of the reservoir near Strumień, the left bank is formed of loess silt soils of considerable thickness. Destruction of the embankment takes place here, in a lesser degree, up to the locality of Wisła Wielka and only in places where the banks are higher and steeper (Fig. 22). Above this locality, in the upper part of the reservoir, greater deformations of banks were not observed. This is probably explained by the more gentler slope of the banks (Fig. 4) and only a slight fluctuation of water on the shallow offshore parts of the reservoir, overgrown by aquatic vegetation. The old protective dikes of the Wisła river, emerging from the water of the reservoir, also have a certain influence and may play the role of breakwaters.

No transformation of the flat right bank is observed in the sector from the dam to the mouth of the Bajerka river. This bank is only subject to superficial erosion within the scope of the wave. The artificial protective dike forming its further sector used to be washed out by waves in the first years, but has lately been reinforced in its major part with concrete slabs.

Final observations

As may be seen from the data presented above, the general transformation of the Goczałkowice reservoir in the first few years after the raising of the water level was not very great. In some more exposed places, however, on the western sector of the left bank, it attained considerable dimensions (from 20 to 35 m.). For comparison, regression of the bank of the Rybinski reservoir in the USSR in conditions of easily washed out morainic soils (clays and sands) amounted to 65 m. in ten years, and that of the Ivankovski reservoir was 55 m. during ten years, in sandy parts of the bank (K a č u g i n 1961).

Observations showed that transformation of the banks in the Goczałkowice reservoir is a steady process. Its intensity was the greatest during the first three years of existance of the reservoir and it proceeds by bounds in the period of not very frequent high and fluctuating water levels and gusty winds. This does not mean that destruction of the banks does not

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take place during average windy weather and low waves. It was observed that banks are washed out by waves of all dimensions.

As results from the calculations of Braslavski (1952) the greatest amount of fluctuation energy reaches the shore line not during the strongest storms, which are usually of short duration, but through a constant but moderate movement of waves caused by often reccuring winds. The heights of waves producing the greatest total amount of energy as calculated by this author are only 0,15- to 0,45 m., equal to those most frequently encountered in the Goczałkowice reservoir.

The most intensive transposition of the line of the bank took place in the northern embankment, exposed to the wind, where the greatest width and depth of the reservoir influenced the greatest fluctuation near the high, steep slopes of the bank formed by easily washed out sandy and silt soils. Sandy soils seem more apt to be washed out, in spite of a resistant layer of loam and although they are overgrown by brushwood near the dam and the intake. This also partly checks the process, but the receding of the line of the bank is considerable here. Destruction of banks composed of silt material takes place in great measure through the tendency to subside of this kind of material. It seems, therefore, that the planting of shrubs and trees on such banks might prove counteractive to a considerable degree.

In the last year of observation, when offshore beaches and underwater shoals on which the waves broke were being formed, regression of the line of the bank was slower. When the water level in the reservoir falls the waves partly wash out the newly formed beaches (Fig. 23).

The action of the waves is not only expressed by the immediate destruction of the embankment — it also washes, transports, sorts, and deposits the washed out material. This activity is performed by stormy compensatory waves beaten away from the bank. Transported earth material in the investigated reservoir causes the water to become troubled only in zones near the shore, for it was noticed that sedimentation mostly takes place at a small distance from the banks. Izjurova (1960) and Kačugin (1959, 1961) state that the major part of bottom sediments accumulate in deep place near the washed out banks. This interesting phenomenon has not been sufficiently investigated by the author to allow the drawing of further conclusions.

During the washing out of the northern bank of the reservoir and depriving of its soil of chemical components (of fluvioglacial and morainic sands and gleyed sub-loess clays) iron and potasium can be washed out in greater quantities. This iron, alongside that carried by the waters of the Wisła and Bajerka rivers (Pasternak 1962) can form a considerable percentage of the iron found in the water and in the emulsion of the reservoir by Bombówna (1962). A large amount of differently grained

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ferriferous concretes is cast ashore on to the surface of its flat right bank by the water of the reservoir.

The present work furnishes only some preliminary data on this subject. A detailed presentation of the problem requires further complex investigations.

I would like to express my sincere gratitude to Professor K. Starmach for entrusting me with this work and Mr J. Starmach for the photographs he furnished. I also thank Mrs M. Szumcowa for meteorological data and Mr Z. Mazur for several photographs showing the initial period of transformation of the banks of the reservoir.

STRESZCZENIE

Autor podaje w pracy wyniki obserwacji i badań, prowadzonych w latach 1958-1962, nad procesem przeformowania się brzegów zbiornika goczałkowickiego w pierwszych latach po jego zalewie. W przedstawieniu stopnia przekształcania się obrzeża zbiornika posłużono się głównie metodą zdjęć, a tylko pomocniczo dokonano pomiarów inżyniersko-geologicznych.

Stwierdzono, że ogólne przeformowanie się obrzeża zbiornika goczałkowickiego w okresie pierwszych lat od spiętrzenia wody było niewielkie. W niektórych jednak miejscach wschodniego odcinka lewego brzegu, dzięki sprzyjającym warunkom, osiągnęło ono znaczne rozmiary sięgające 20—35 m (ryc. 11-19).

Zaobserwowano, że przekształcenie się brzegów zbiornika goczałkowickiego jest procesem ciągłym, najbardziej intensywnie przebiegającym w pierwszych 3 latach istnienia zbiornika, i to na ogół skokami w okresie dość rzadkich w tym zbiorniku wysokich i wahających się poziomów wody (ryc. 2) oraz porywistych wiatrów. Nie znaczy to jednak, że niszczenie brzegów nie zachodzi przy przeciętnej wietrznej pogodzie i niskim falowaniu. Stwierdzono, że brzeg rozmywają fale wszystkich wymiarów. Maksymalna zanotowana prędkość wiatru na zbiorniku wynosi 20 m/sek. a wysokość fali 2,5 m. Średnia roczna prędkość wiatru waha się około 2,2 m/sek. (ryc. 3), a najczęstszą wysokością fal jest 0,15—0,45 m.

Największe przesunięcia linii brzegowej wystąpiły na nawietrznym północnym obrzeżu w miejscu o największej szerokości i głębokości zbiornika (największe falowanie), przy wysokich i stromych stokach tego brzegu (ryc. 8, 9, 10), zbudowanych z łatwo rozmywanych gleb piaszczystych i pyłowych (tab. I), przy czym więcej rozmywane wydają się gleby piaszczyste. Niszczenie brzegów zbudowanych z utworów pyłowych zachodzi w dużej mierze na skutek skłonności do obsuwania tego rodzaju materiałów.

W ostatnim roku obserwacji w miarę formowania się przybrzeżnych plaż (ryc. 21, 23) i podwodnych mielizn, załamujących fale, cofanie się linii brzegowej było wolniejsze. Przy opadającym poziomie wody w zbiorniku fale rozmywają w części ponownie wytworzone plaże (ryc. 23).

Praca fal wyraża się nie tylko w bezpośrednim niszczeniu obrzeża, lecz także w długotrwałym przemywaniu, przenoszeniu, sortowaniu i osadzaniu rozmytego materiału. W badanym zbiorniku unoszony materiał ziemny powoduje zmętnienie tylko przybrzeżnych stref wody, gdyż w niedużych odległościach od brzegu następuje w większości jego osadzanie.

Podczas rozmywania północnego brzegu zbiornika, ze składników chemicznych gleby (piasków fluwioglacjalnych i morenowych oraz oglejonych glinek podlessowych) mogą być wypłukiwane przez wodę w większych ilościach żelazo i potas.

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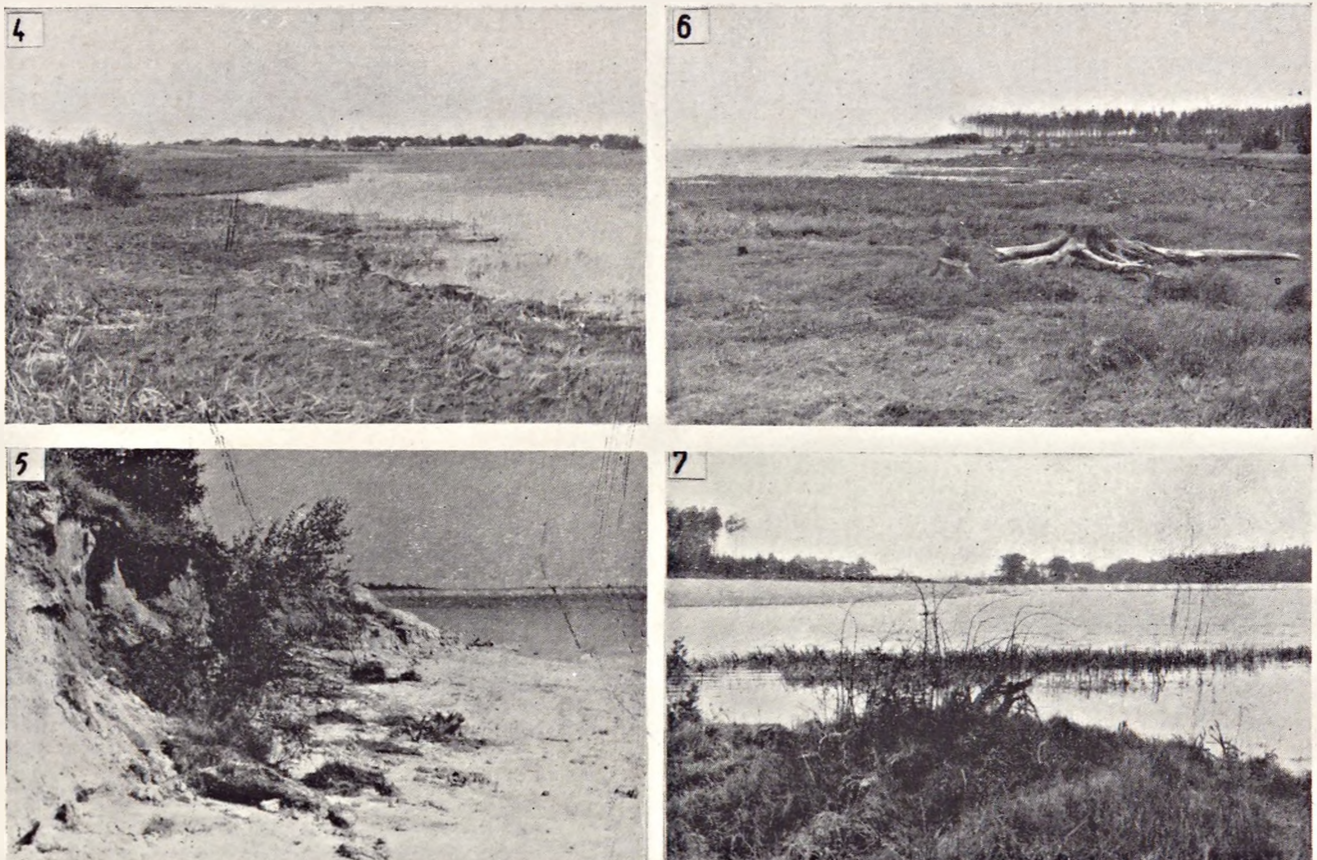

Fig. 4-7. Fragments of reservoir banks: 4. left bank in the region of Wielka Wisła; 5. Goczałkowice; 6. right bank near Podjazd; 7. protective dike near Frelichów reinforced with concrete (Phot. J. Starmach)

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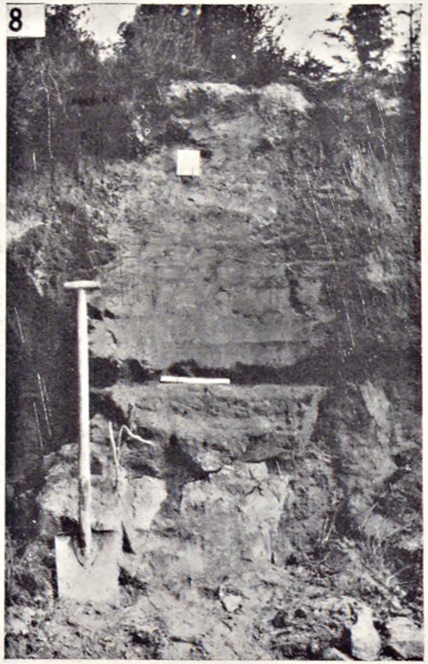

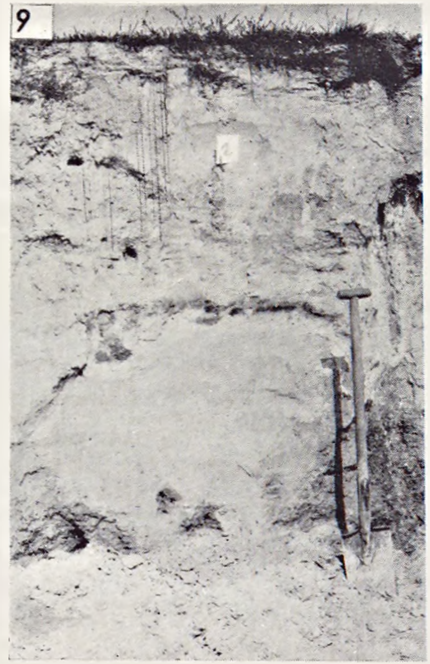

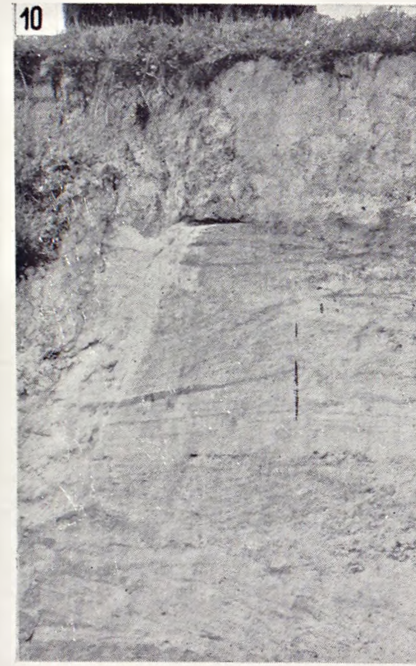

Figs. 8-10. Typical soil profiles of the northern destructible embankment in the localities: 8. Goczałkowice; 9. Łąka; 10. Wisła Wielka (Phot. J. Starmach)

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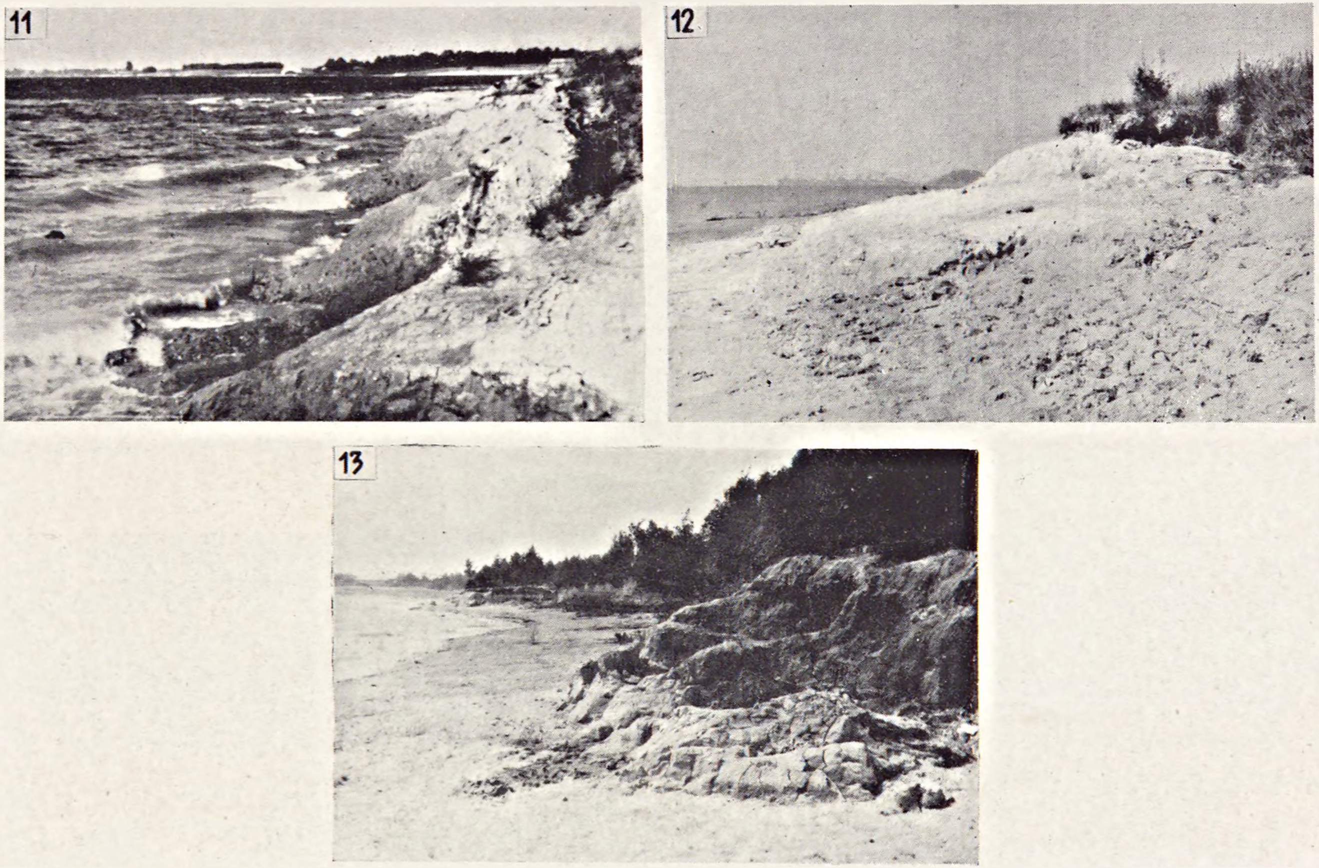

Figs. 11-13. Sector of the washed out embankment between the dam and the intake: 11. in 1957; 12. in 1959; 13. in 1962. (Figs. 12, 13 phot. J. Starmach)

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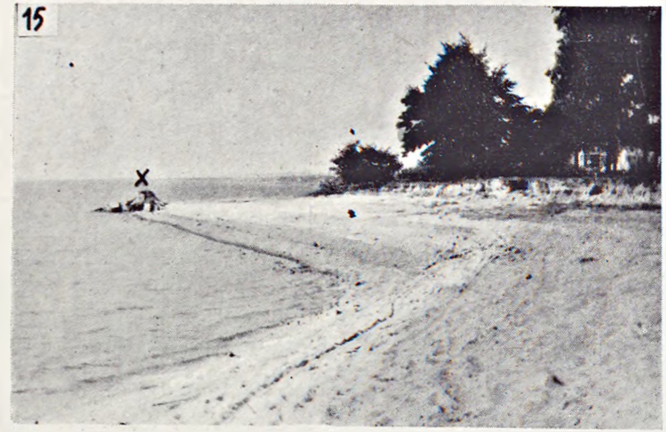

Figs. 14-16. Transformation of the bank between the water intake and the village Łąka with a view of the oak trunk (x) forming a stable point: 14. in 1957; 15. in 1959; 16. in 1962. (Figs. 15, 16 phot. J. Starmach)

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Figs. 17-19. Transformation of the bank in Łąka, near the house No 227: 17. in 1957; 18. in 1959; 19. in 1962.
(Fig. 18, 19 phot. J. Starmach)

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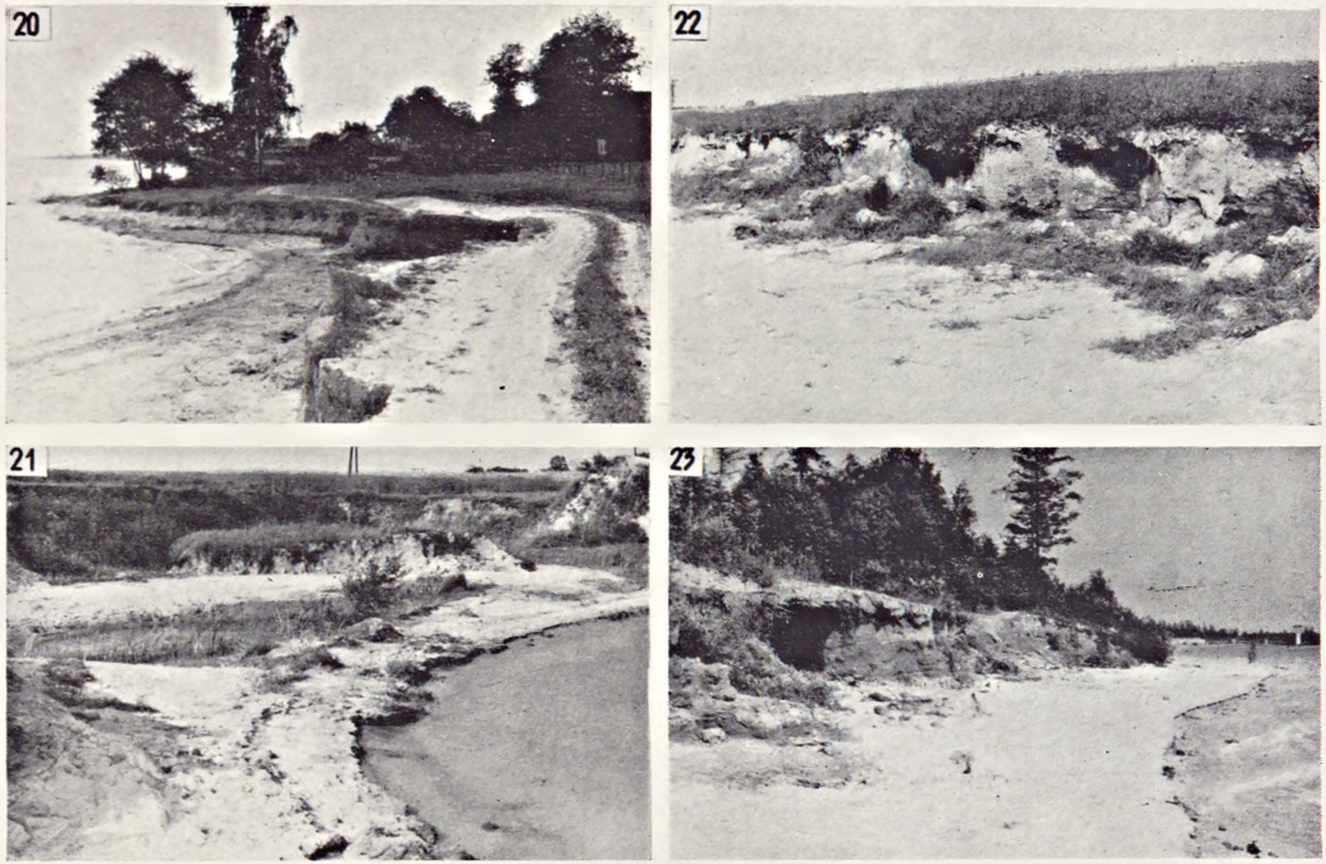

Fig. 20. Encroachment of the reservoir into cultivated fields between the water intake and the village Łąka
Fig. 21. Fragment of the beach formed on the terrain of the former sand-pit
Fig. 22. Undermined banks in the neighbourhood of Wielka Wisła
Fig. 23. View of the destructive secondary action of waves on the previously formed shore (Phot. J. Starmach)

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