Geomorphological effects of the Rømø Dam: development of a tidal channel and collapse of a dike

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The Rømø Dam has had positive, but also negative effects on the surrounding wadden sea area. This paper describes the negative influence of the dam on the east coast of Rømø. Registrations have been carried out since 1951.

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In the years 1939-48 a 10-km long dam was constructed from Jutland to the island of Rømø. The easternmost 6 km of the dam were built upon the watershed between two tidal areas, while the westernmost 4 km are situated south of the watershed cutting a tidal channel, called Fuglegrøften (Fig. 1). The latter was formerly buoyed and used by ships sailing along the east coast of Rømø. It had to be given up, however, because of the tidal flat Vesen, which emerged by accumulation of material within the zone of the watershed. An aerial photograph from 1945 (Fig. 2) taken just prior to the completion of the dam shows the detailed surface forms of the watershed. Most essential in this connection is the extremely ramified system of tidal creeks draining the zone of the watershed toward the SW to Fuglegrøften and toward the NE to Rømø Leje. Upon completion of the Rømø Dam a drainless basin was formed between the dam and the watershed; its water level was 0.2 m DNN corresponding to the elevation of Vesen. The tidal creeks on the southwestern side of Vesen had now become inefficient, whereas the creeks toward Rømø Leje began to erode headward through the tidal flat. The erosion took place most rapidly in the creek nearest the east coast of Rømø, the main reason being that this creek was much less influenced by the flood current through the Rømø Leje than the other creeks (B. Jakobsen, 1962). Another reason may be the

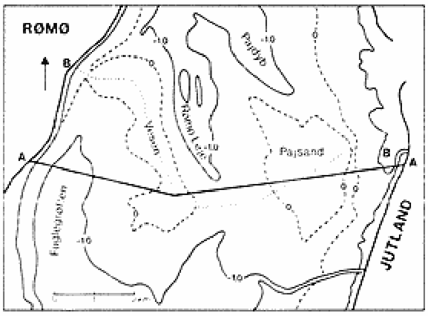

Fig. 1. Contour map from 1936 of part of the wadden sea between Rømø and Jutland. Contour lines in m DNN (Danish Ordnance Datum). A-A projected dam. B-B watershed.
Fig. 1. Højdekort fra 1936 over del af Vadehavet mellem Rømø og Jylland. Koter i m DNN. A-A projekteret dæmning. B-B vandskel.

Fig. 2. Aerial photo from 1945 of the watershed area east of Rømø. 1-1 watershed. Scale 1:40 000.
Fig. 2. Flyfoto fra 1945 af vandskelsområdet øst for Rømø. 1-1 vandskel. Målestoksforhold 1:40000 (Royal Air Force).

Fig. 3. Aerial photo from 1973 of part of the Juvre Priel. 1. ebb channel. 2. flood channel. 3. flood bar. 4. levees. 5. tidal creek. 6-6. Juvre Dike. Approximate scale 1:12 500.
Fig. 3. Flyfoto fra 1973 af del af Juvreprielen. 1. ebbeskår. 2. flodskår. 3. flodbanke. 4. leveer. 5. vadepriel. 6-6. Juvrediget. Omtrentlig målestok 1:12 500. Reproduceret med tilladelse A 251/84, Geodætisk Institut. 1973.05.28.

location of the creek off the lowest, the narrowest, and the most easily erodable part of the watershed corresponding to the former Fuglegrøft channel. The watershed was consequently breached through in this place, forming a basin drain to the north. In this way the formation of a new tidal channel, the Juvre Priel, was initiated.

The morphology of the Juvre Priel

In the Juvre Priel area the following characteristic tidal elements can be observed: ebb- and flood channels, flood bars, levees, and tidal creeks (Fig. 3). The ebb channel is the principal channel – mainly shaped by the ebb current – most often having distinct meandering tendencies. A flood channel is a blind tributary channel – mainly shaped by the flood current – short and almost rectilinear. In connection with flood channels, flood bars emerge consisting mainly of material transported by the flood current. The flood bar is crescent- or horseshoe-shaped (Børge Jakobsen, 1962). Levees mainly occur along the concave side of the meander curves of ebb channels and

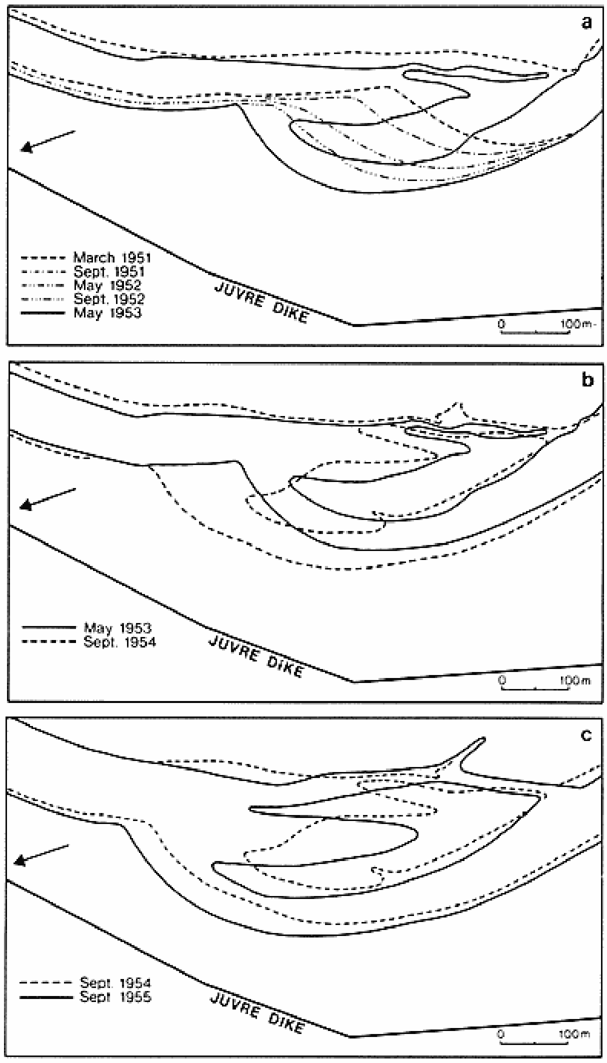

Fig. 4. The development of ebb channel, flood channel and flood bar in the Juvre Priel 1951-55. The tidal elements are shown by low-water lines.
Fig. 4. Udviklingen af ebbeskår, flodskår og flodbanke i Juvreprielen 1951-55. Formerne er vist ved lavvandslinier.

consist of material transported by the flood current. Tidal creeks occur along the banks of tidal channels draining a limited area.

The development of the Juvre Priel

The first mapping of the Juvre Priel was made in 1951, and since then the development within the area has been closely observed. A large number of systematic measurements has been carried out, especially of the tidal elements: ebb- and flood channels, and flood bars, whose development during the period 1951-82 will be described in the following.

The mapping of 1951 shows that the Juvre Priel was a neutral channel without separate flood- and ebb channels, but with a distinct meandering tendency. Fig. 4a shows the development of a section of a meander curve from 1951 to 1953, and it is seen that the concave side was rapidly migrating landward simultaneously with a displacement of the curve in a northern direction. In the course of one year, from March 1951 to May 1952 the meander curve eroded away a total wadden area of 2.2 ha, hereof the 0.9 ha from March to September and the 1.3 ha from September to May. The following year the total loss was 2.3 ha, hereof 0.9 ha eroded away from May to September 1952, and 1.4 ha from September 1952 to May 1953. The monthly average erosion was for the two summer periods 0.18 ha and for the two winter periods 0.17 ha. This means that the erosion was just as heavy in summertime as in wintertime. The decisive factor is wind action and water-level. The erosion is greatest during strong, easterly winds, since winds from the east cause extreme low-tides and consequently a strong ebb current which, in conjunction with wave action, has a vigorously eroding effect on the east-facing western wadden bank. It can be mentioned that, during a southeastern gale, a landward displacement of 3.5 m was observed of the western bank over a period of 48 hours. During strong and frequent westerly winds the erosion capability of the Juvre Priel is greatly diminished, because the high water-levels, generally remaining above wadden level, reduce wave erosion in the banks; moreover, they induce only relatively weak currents due to the fact that for the greatest part of the tidal period the water movements are not forced to follow the channels, but flow freely all over the area.

The mapping from 1953 shows that the Juvre Priel was no longer a neutral channel, as a flood bar was emerging in the area eroded away mainly by the ebb current. The flood bar had not yet reached horseshoe shape, but was markedly asymmetrical with a weakly developed easternmost branch. The following year, from 1953 to 1954, the northward displacement of the meander curve was continuing (Fig. 4 b). For this period, the eroded area totals 2.7 ha, the western bank of the meander being only 130 m from the dike in 1954 against 180 m in 1953. The flood bar had grown by almost 50%, but was still asymmetrical.

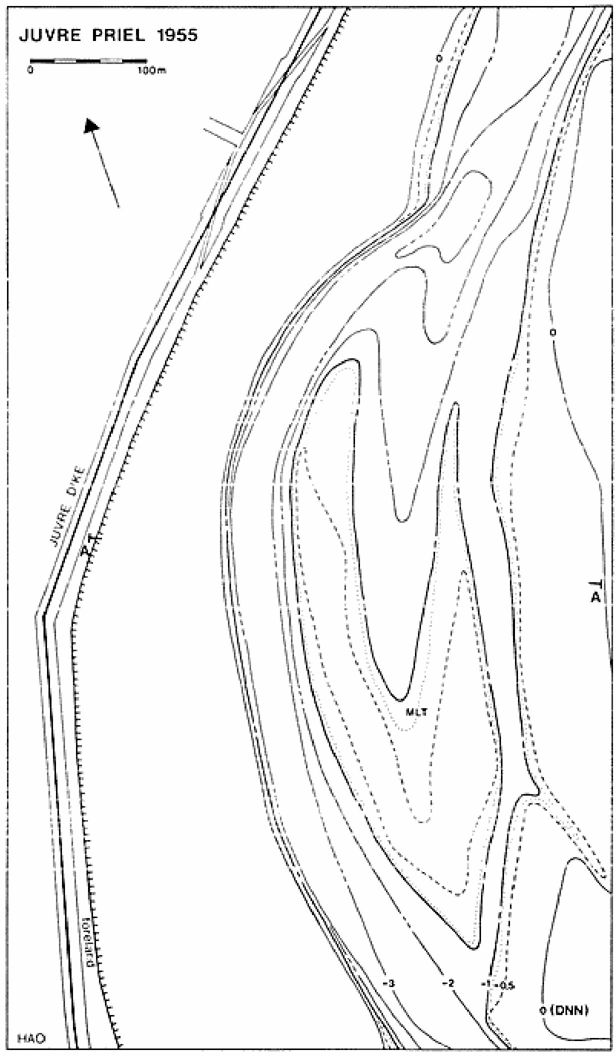

Fig. 5. Contour map from 1955. MLT: mean low-water line.
Fig. 5. Højdekort fra 1955. MLT: middellavvandslinie.

The area of the westernmost branch of the flood bar was both for 1953 and for 1954 roughly 5 times greater than the easternmost branch. From 1954 to 1955 the erosion by the meander was much less than the foregoing year, with a loss of area of only 1,7 ha. By now, the meander curve was being displaced toward the northwest instead of toward the north, and the western bank of the meander had now moved an additional 40 m towards the dike, so that, in 1955, the distance had been reduced to 90 m (Fig. 4c). The flood bar was now approaching the symmetrical horseshoe shape, the western branch being only 1.5 times the size of the eastern one. Between the two branches a well developed flood channel could be observed. The flood bar was clearly separated from the wadden east of it by a 20-40 m broad channel. The eastern border of this channel corresponds to the original eastern bank of the Juvre Priel.

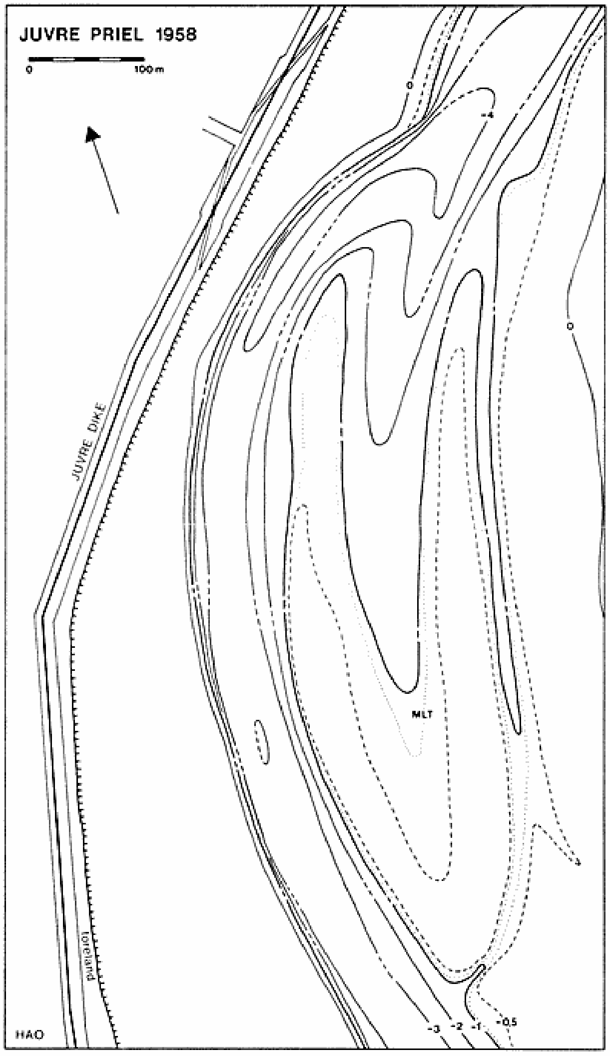

Fig. 6. Contour map from 1958.
Fig. 6. Højdekort fra 1958.

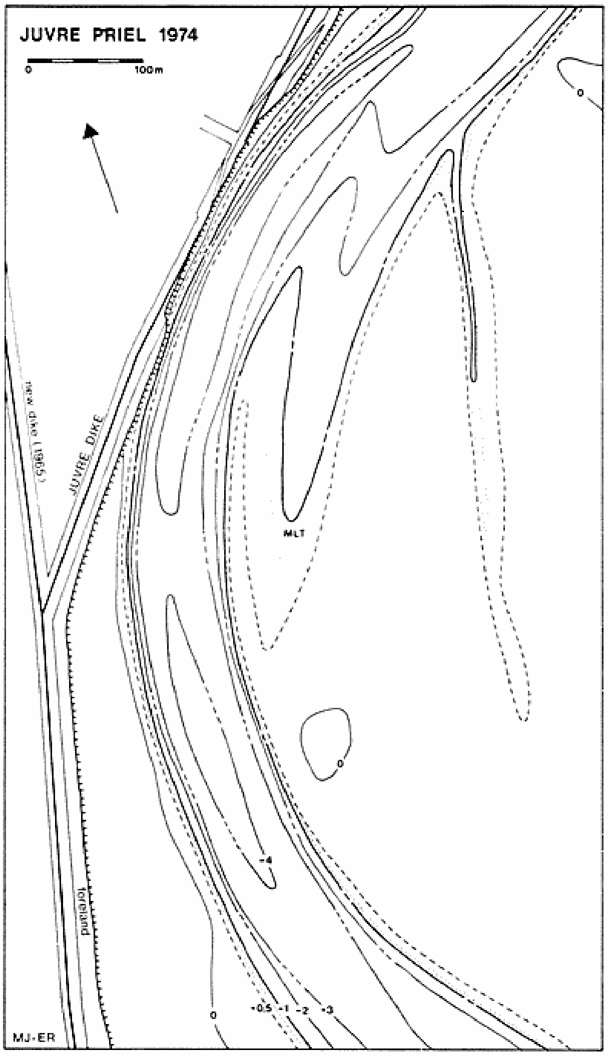

Fig. 7. Contour map from 1974.
Fig. 7. Højdekort fra 1974.

The development from 1955 to 1982 is shown on the contour maps, Figs 5-8. At the beginning of the period, from 1955 to 1958, the migration speed of the meander curve was decreasing; the total loss in area was only 2.8 ha, or approximately 0.9 ha per year. In 1958, the western bank of the ebb channel was located roughly 50 m from the dike; this means the same displacement in three years as previously in one year. The direction of migration was still northwesterly, i.e. almost at right angles to the dike. In the following years the landward migration of the meander continued. By 1963, the ebb channel had eroded its way up to the foreland, by 1967 up to the base of the dike, and in 1974 it had reached the core of the dike. From 1958 to 1974 the total loss of area amounted to 5.2 ha. For the periods 1958-63, 1963-67, and 1967-74 the average annual losses have been calculated to be 0.5 ha, 0.3 ha, and 0.2 ha respectively. This clearly shows that the landward migration speed was still decreasing. The trend continued for the period 1974-82, when the average annual loss in area is less than 0.2 ha. Along with the decrease in migration speed of the meander curve, the ebb channel was deepened. In the part of the ebb channel shown in Figs 5-8 the total area with depths greater than -4 m DNN had increased by 2 ha from 1955 to 1982. In 1982 even an area with depths greater than -5 m DNN was observed.

The morphological complex of flood bar and flood channel has been constantly increasing for the whole period 1955-82 (Table 1); during this period the share of the flood bar increased from roughly 70% to more than 90%. In the same period the shape of the flood bar changed markedly. From 1955 to 1958, the development continued towards a regular horseshoe shape through a marked increase in area of the easternmost branch, which

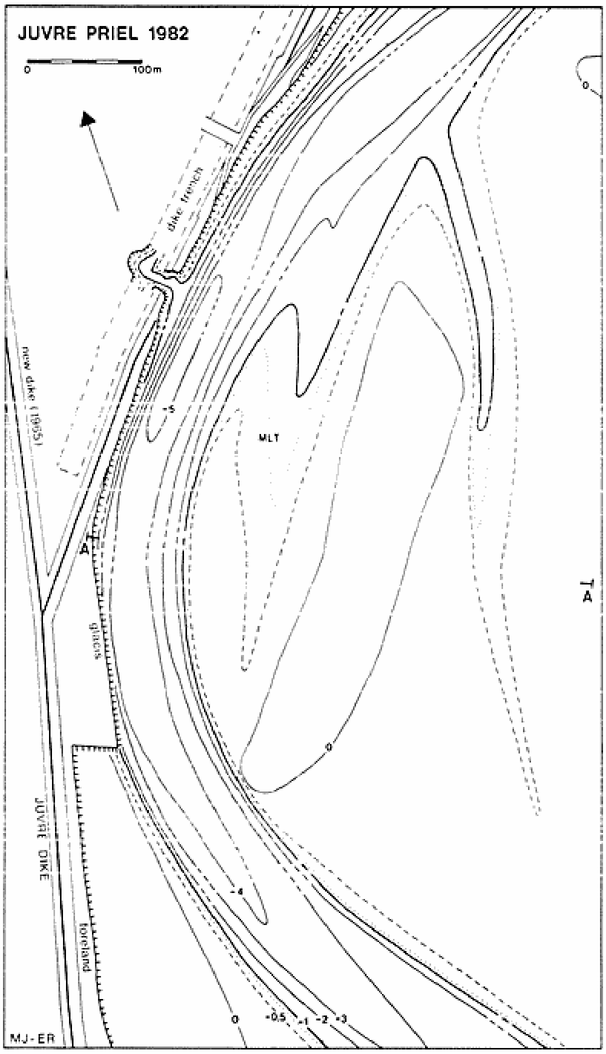

Fig. 8. Contour map from 1982.
Fig. 8. Højdekort fra 1982.

moreover in 1958 had reached a greater height than the westernmost in contrast to what was the case in 1955. This change initiates a new phase in the development of the flood bar. Again it became irregular, but now due to a vigorous development of the easternmost branch both with regard to area as well as height. During this phase the flood bar achieved a height above DNN for the first time. In 1974, an area of 0.2 ha could be observed above this level and, in 1982, it had increased to 3.3 ha. Up to 1958, the area of the flood channel increased along with the formation of the flood bar (Figs 4-6). As with the flood bar, there was likewise a fundamental change in the development of the flood channel from 1958. From this year on the flood channel was being filled up to a great extent. Thus areas with depths below – 1 m were about 5 times the size in 1958 as compared with 1982, and in 1958 depths below -2 m could be observed, a value which does

Year	Total area ha	Area >0 m ha	Area >0 m o/o	Area >-1 m ha	Area >-1 m o/o	Area <-1 m ha	Area <-1 m o/o	Area <-2 m ha	Area <-2 m o/o
1955	6,2	0	0	4,5	73	1,7	27	0,4	6
1958	9,3	0	0	6,9	74	2,4	26	0,6	6
1963	10,9	0	0	8,9	82	2,0	18	0,4	4
1967	11,6	0	0	9,7	84	1,9	16	0,3	3
1974	12,7	0,2	2	11,5	91	1,2	9	0,1	1
1982	13,9	3,3	24	13,4	96	0,5	4	0	0

Table 1. The flood channel/flood bar complex. Area on different levels in hectares and in per cent of the total area.
Tabel 1. Flodskår/flodbanke komplekset. Arealfordeling på niveauer i hektar og i procent af det totale areal.

not occur in 1982 (Table 1). As mentioned above, the eastern border of the flood bar was a channel which, in 1958, still connected the northern and the southern part of the ebb channel in that along its whole length, it had depths below low-tide level. After 1958 the channel filled up resulting in a break in the connection to the southern part of the ebb channel. In 1974, the channel had been reduced to a tidal creek with outlet into the northern part of the ebb channel. In 1982 there was an apparent tendency towards a new increase in size of the creek.

In the following, the development of the Juvre Priel from 1955 to 1982 (cf. Fig. 9) is summed up. The ebb channel has been displaced – at decreasing speed – in a northwestern direction, simultaneously becoming both deeper and wider. Likewise, the flood channel has been displaced toward the northwest along with the dislocation of the ebb channel. At the same time the size of the flood channel is diminishing. The flood bar is growing both in area and in height. It is asymmetrical both in 1955 and in 1982, but has changed fundamentally in shape during this period. In 1955 the western branch is the most developed in contrast to 1982 when the eastern branch is the dominating one. The channel along the eastern bank of the flood bar has been stationary during the whole period and represents thus still in 1982 the original eastern bank of the Juvre Priel (Fig. 4). Sedimentation has blocked the connection to the southern part of the ebb channel, however. The development recorded of the Juvre Priel regarding the displacement of the ebb channel, the growth of the flood bar and its changing asymmetry as well as the filling up of the flood channel are all in accordance with the theories advanced by Børge Jakobsen on the morphologi-

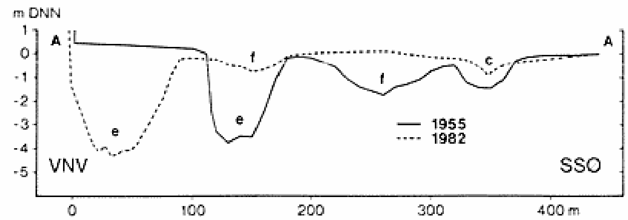

Fig. 9. Cross profile of the Juvre Priel (A-A Figs. 5 and 8). e. ebb channel. f. flood channel. c. tidal creek.
Fig. 9. Tværprofil af Juvreprielen (A-A fig. 5 og 8). e. ebbeskår. f. flodskår. c. vadepriel.

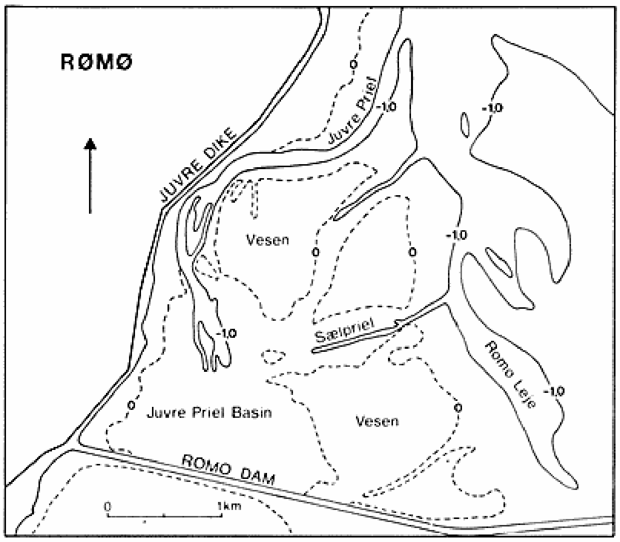

Fig. 10. Contour map from 1956 of the original watershed area.
Fig. 10. Højdekort fra 1956 over det oprindelige vandskelsområde.

cal development of tidal channels in his works on the morphology of the Danish Wadden Sea (B. Jakobsen, 1962 and 1964).

Attempts to control the Juvre Priel

As early as in 1951 it was realized that the erosion by the Juvre Priel might damage the Juvre Dike on the eastern coast of Rømø. An attempt was made to establish a new outlet from the Juvre Priel basin (Fig. 10) by digging a canal from the western part of the Sælpriel to the basin, unfortunately with no success. So, in 1959, a canal was blasted instead. At the same time a canal was blasted through the flood bar of the Juvre Priel (Fig. 11). Neither did these measures give a lasting result, the blasted canals very rapidly filled up with sand. The main reason is that both these areas are dominated by the bar formations of the flood current. In 1966 a relief canal was dug on the wadden east of the flood bar in order to establish a connection between the Juvre Priel basin and the northern part of the ebb channel. To the west, the canal was supported by a brushwood groyne, part of which can be seen in Fig. 3, and, to improve its function, artificial seaweed was spread out over 1500 m² south of the flood bar. It proved impossible, however, to force the ebb current of the Juvre Priel through the relief canal which is today completely blocked by sanding up. Together with the attempts to establish new drainage possibilities from the Juvre Priel basin, it was tried to decrease the volume of the basin by land reclamation. The first sedimentation basins were established in 1958, and have since been maintained and even extended. The effect of them has hitherto been limited, however, as they only comprise a minor part of the basin.

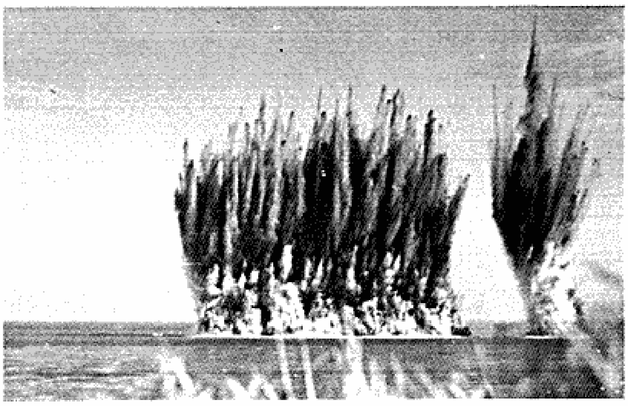

Fig. 11. The blasting in 1959 of a canal through the flood bar.
Fig. 11. Sprængning af rende gennem flodbanke i 1959. (Foto: M. Jespersen).

The collapse of the Juvre Dike

The Juvre Dike was built 1926-28 in order to protect 640 ha of northeastern Rømø. The height of the dike is 5 m DNN, and it consists of material dug out just west of the dike, whereby the dike trench was formed which is seen in Figs 3 and 8. The core of the dike consists of a mixture of sand and marsh clay lumps, while the surface of the dike has an irregular cover of marsh clay. The dike was established on the edge of a marine foreland situated in level 1.5 m DNN and mainly consisting of homogeneous marsh clay. Shortly after completion of the dike, a glacis of concrete slabs was constructed for protection of the foreland which was being eroded by waves. In 1962, the western bank of the ebb channel was situated roughly 4 m from the foreland. At that time most of the concrete glacis was deteriorated by weathering so the foreland was left unsheltered. It was therefore decided to reinforce the foreland by means of brushwood groynes. However, these soon proved to be worthless. As previously mentioned, the Juvre Priel had already in 1967 eroded its way into the base of the dike. At that time the brushwood groynes had been eroded away along a distance of roughly 250 m, but already prior to that, it was realized that part of the dike had to be given up and, in 1965, a recessed dike was established (Fig. 3). In 1974 the erosion had exposed 150 m of the dike core and, in 1982, an additional 50 m. By bow, the coast was under erosion for a length of 400 m. Consequently, the dike has been very vulnerable for the last decade, and during the storm surge on November 24, 1981, the dike crest was breached at several places. During the surge, the maximum water level between the two dikes was approximately 4.3 m DNN. After the surge, the water-level dropped to roughly 3 m DNN, corresponding to the minimum height of the remaining dike core. By now, a water volume of about 250.000 m³ had become trapped between the two dikes, and not until 3 days later did the water succeed in finding an outlet from the area by

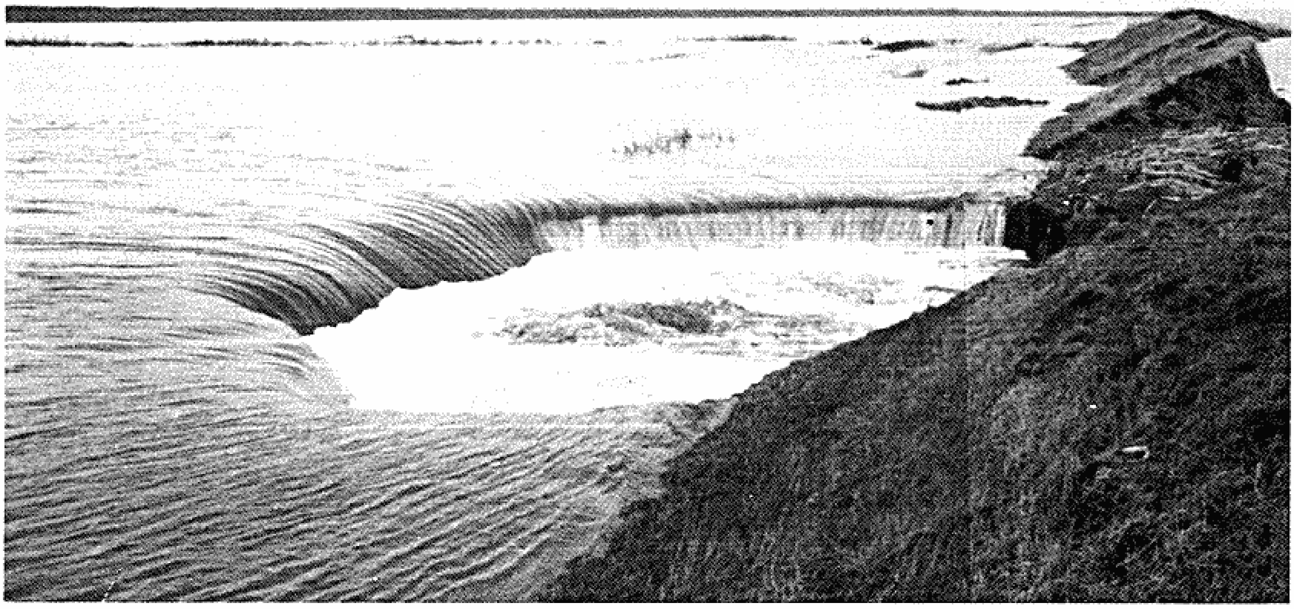

Fig. 12. The area between the old and the new Juvre Dike after the storm surge in 1981. The trapped water has breached through the dike and flows out into the Juvre Priel forming a cascade.

Fig. 12. Området mellem det gamle og det nye Juvredige efter stormfloden 1981. Den indespærrede vandmasse har gennembrudt diget og strømmer ud i Juvreprielen under dannelse af et vandfald. (Foto: E. Rasmussen).

breaching the dike from the inside. How this breach happened was observed by the late Lehman Petersen, Rømø, who gave an account hereof to the authors, which is outlined below:

On Friday the 27th of November 1981, the low-tide in the Juvre Priel was about 9.a.m. At 10.10 it was observed that water was overflowing the dike in a 1-cm thick layer in two places, each 1-2 m long. Furthermore, a weak seeping could be observed about 1 m under the surface of the foreland. At 10.30 two longitudinal cracks appeared in the dike. The distance between the parallel cracks was about 30 cm. East and west of them, marsh clay was found, and between the cracks there was sand. About 1.5 m below the surface of the foreland, there was a hole with a diameter of about 10 cm. From this hole, clear water gushed forth as from a spring. At 10.40 the sand between the cracks had sunk about 2 cm, and the water welling up from the hole was now alternately clear and muddy. Gradually, the sand subsided about 50 cm, while the clay on the sides remained. Then, the sand suddenly subsided about 75 cm and simultaneously a seepage occurred over a longer stretch at the level of the surface of the foreland. The hole further down had now become covered by the beginning flood in the Juvre Priel. So far, the water has overflowed both clay crests and the subsiding sand. After the sudden subsiding of the sand, the water crossed only the inner clay crest, and from there it percolated the sand and seeped out on the outer side of the dike. The outer clay crest, which had by now become dry, gradually collapsed due to undermining, cracked and fell out into the Juvre Priel in larger pieces. About noon the outer clay crest had disappeared, the last sand was washed away, and the overflowing water began to erode the eastern side of the inner clay crest, after which it too collapsed. From now on, the water ran unhindered through the dike, and the vigorous current rapidly eroded a deep channel into the foreland. Later measurements showed that this channel reached a depth of -1.5 m DNN. Inside the dike breach a cascade soon developed (Fig. 12), which, during the next hours, eroded its way into the marsh area on the western side of the dike trench, and there, shaped a regular, semi-circled hole (Fig. 13) with a radius of 10 m and maximum depth of -1.7 m DNN.

After the breach of the dike in 1981, several measures have been taken to secure the eastern coast of Rømø. In 1983 the remains of the destroyed dike were dug up, and the material was used to reinforce the recessed dike. Moreover, a 0.5 ha large wadden area south of the breach was filled up in 1982 (Fig. 8) and, towards the Juvre Priel, secured with a glacis of large blocks. The future investigations in the area will primarily focus upon the effect of this human interference on the morphological development of the ebb- and flood channels as well as flood bars of the Juvre Priel.

Fig. 13. Semicircular hole formed by headward erosion after the storm surge in 1981 (Fig. 12). On the former cultivated area between the two dikes (Fig. 3) a sparse vegetation of Salicornia is found.

Fig. 13. Halvcirkelformet hul udformet ved tilbagegående erosion efter stormfloden i 1981 (fig. 12). Det tidligere opdyrkede område mellem de to diger (fig. 3) er nu bevokset med spredte kveller. (Foto: E. Rasmussen).

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Resumé

Ved bygningen af Rømødæmningen blev der dannet et afløbsløst bassin mellem dæmningen og det naturlige vandskel (fig. 1 og 2). Dette vandskel blev gennembrudt ved tilbagegående erosion af en priel, Juvreprielen. På basis af talrige kortlægninger gives en beskrivelse af Juvreprielens udvikling fra 1951 til 1982 med særligt henblik på formerne ebbeskår, flodskår og flodbanke (fig. 3). En kortlægning fra 1951 viser prielen som et neutralt løb med mæandertendens. I 1953 er prielen opdelt i flod- og ebbeskår (fig. 4). Fra 1953 til 1958 forskydes ebbeskåret ind mod diget. Arealet af flodskår og flodbanke vokser, samtidig med at flodbanken bliver symmetrisk omkring flodskåret (fig. 4-6). Fra 1958 til 1982 forskydes ebbeskåret helt ind til diget, samtidig med at dybde og bredde øges. Flodskåret er under opfyldning, og flodbanken vokser i areal og højde. Flodbanken bliver igen stærkt asymmetrisk (fig. 6-8).

Siden 1951 har man forsøgt at standse prielens vandring mod diget bl.a. ved sprængning af nye afløbsrender (fig. 11). Alle forsøg var forgæves, og i 1965 byggedes et tilbagetrukket dige (fig. 3). Allerede i 1974 var 150 m af digekernen blotlagt (fig. 7). Ved stormfloden 1981 blev digekronen gennembrudt, og området mellem de to diger overskyllet. Den indespærrede vandmasse fik afløb ved at gennembryde diget indefra (fig. 12) under dannelse af et halvcirkelformet hul i marsken (fig. 13). I 1982 blev prielens vandring forsøgt standset ved opfyldning og anlæggelse af et kraftigt glacis (fig. 8). De videre undersøgelser af Juvreprielens morfologiske udvikling vil primært være centreret om effekten af dette indgreb.

Fig. 13. Semicircular hole formed by headward erosion after the storm surge in 1981 (Fig. 12). On the former cultivated area between the two dikes (Fig. 3) a sparse vegetation of Salicornia is found.

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Resumé

Ved bygningen af Rømødæmningen blev der dannet et afløbsløst bassin mellem dæmningen og det naturlige vandskel (fig. 1 og 2). Dette vandskel blev gennembrudt ved tilbagegående erosion af en priel, Juvreprielen. På basis af talrige kortlægninger gives en beskrivelse af Juvreprielens udvikling fra 1951 til 1982 med særligt henblik på formerne ebbeskår, flodskår og flodbanke (fig. 3). En kortlægning fra 1951 viser prielen som et neutralt løb med mæandertendens. I 1953 er prielen opdelt i flod- og ebbeskår (fig. 4). Fra 1953 til 1958 forskydes ebbeskåret ind mod diget. Arealet af flodskår og flodbanke vokser, samtidig med at flodbanken bliver symmetrisk omkring flodskåret (fig. 4-6). Fra 1958 til 1982 forskydes ebbeskåret helt ind til diget, samtidig med at dybde og bredde øges. Flodskåret er under opfyldning, og flodbanken vokser i areal og højde. Flodbanken bliver igen stærkt asymmetrisk (fig. 6-8).

Siden 1951 har man forsøgt at standse prielens vandring mod diget bl.a. ved sprængning af nye afløbsrender (fig. 11). Alle forsøg var forgæves, og i 1965 byggedes et tilbagetrukket dige (fig. 3). Allerede i 1974 var 150 m af digekernen blotlagt (fig. 7). Ved stormfloden 1981 blev digekronen gennembrudt, og området mellem de to diger overskyllet. Den indespærrede vandmasse fik afløb ved at gennembryde diget indefra (fig. 12) under dannelse af et halvcirkelformet hul i marsken (fig. 13). I 1982 blev prielens vandring forsøgt standset ved opfyldning og anlæggelse af et kraftigt glacis (fig. 8). De videre undersøgelser af Juvreprielens morfologiske udvikling vil primært være centreret om effekten af dette indgreb.