

***TOPIC 5. BASICS AND FOUNDATIONS IN
CONDITIONS OF FLOODED TERRITORIES***

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FLOODING OF TERRITORIES BY GROUND WATERS

Groundwater flooding is an engineering-geological process that manifests itself in certain environmental conditions in urban areas and agricultural lands, in which there is a rise in groundwater (GW) table and a significant increase in soil moisture. When GW levels are excessive, construction conditions and operation of buildings and structures are disrupted and there are destruction of green spaces, salinization and waterlogging of land (Fig. 1). This process occurs due to the combined impact of a whole range of causes and factors of both natural and anthropogenic (technogenic) origin.



Fig. 1. Waterlogging during flooding

THE MAIN TECHNOGENIC CAUSES OF FLOODING OF CITIES AND SETTLEMENTS INCLUDE THE FOLLOWING:

- changing conditions of surface runoff (the absence of vertical layout and drainage networks, the intersection of surface runoff paths with roads and embankments, the creation of cascades and reservoirs on small rivers, among others);
- backfilling of natural drains – ravines, gullies, small streams, lakes;.
- reduction of evaporation and condensation of moisture in the soils of the aeration zone as a result of the effect of shielding by buildings;
- shortcomings in the device of sewage or its absence;
- a developed water supply network but poor domestic sewage networks;
- barrage effect of embankments of roads, foundations of buildings, pile fields, large collectors and subways;
- large leakage of water from water-bearing networks and other water bodies;
- the influence of industrial enterprises with wet production technologies;
- closing and flooding of coal and other mines.

In accordance with standards “Engineering protection of territories and structures from flooding“, the following types of territories are distinguished:

Flooding caused by a surge of soil moisture, a rise of groundwater level or flood that has already led or could lead in the future (according to forecasts) to a significant deterioration in the living conditions of the population and economic activities. In separate areas of the flooded territories, various stages of development of the processes of flooding are observed.

Flooded territories where groundwater rises permanently or temporarily for a sufficiently long period (month or more) above the maximum depths, increase in groundwater level and flooding, which significantly affect the operation of economic facilities in regulated mode. This does not take into account accidental emergencies.

Flooded areas in need of urgent protection are areas related to flooded territories in which an emergency situation has arisen due to flooding and its consequences, often leading to unsatisfactory sanitary and ecological conditions.

Potential flood prone territories are areas where conditions for their attribution to the flooded territories have not yet developed, but this is possible by the forecast or by an analysis of existing factors and reasons related to construction or retaining structures. These are territories with high occurrence of water-resistant layers, soils with lithological structure and relief, which contribute to the accumulation of sediments, infiltration of waters, including leaks from water-bearing networks.

**Table 1. Limit depths of groundwater for territories of cities and towns
(according to DBN B.1.1-25-2009)**

Purpose of the territory	Maximum depth to groundwater level, m	Notes
Multi-storey capital development:		
if the freezing depth is 0.7 m or more	Not less than 2.0	not less than 0.5 m from the soles of the foundations of structures
the same, less than 0.7 m	Not less than 1.5	Same as above
With basements	From the basement floor not less than 1.0	Same as above
With developed underground space (underground pedestrian and transport facilities, communication tunnel channels and collectors)	not less than 0.5 m from the floor of buried structures	
Low-rise manor-house	Not less than the depth of freezing	Same as above
Streets, roads, squares no less		Same as above
Intercity motorways within cities and towns	Same as above	Not less than the depth of normal tree growth *
From the bottom of drinking water pipelines	Local water supply is required for capital construction	
Parks, squares, green spaces	Not less than the depth of freezing	Same as above
Stadiums, playgrounds, other planar structures		Same as above
* Limit values of groundwater depths required for normal tree growth: poplar – 0.4 m; pine – 1.0 m; fruit trees – 1.0–1.5 m; birch – 1.5 m; for other tree species – according to special reference books		

Measures for engineering protection against flooding are subdivided into *preventive measures and construction of engineering protective structures*.

The main preventive measures are as follows:

- Artificially increasing the planning marks of the earth's surface in the protected area (Fig. 2);
- compliance with regulatory requirements for compaction of the soil when backfilling pits and trenches;
- ensuring reliable drainage of surface water by means of storm sewers, compliance with slopes of asphalt and concrete surface coatings;
- ensuring the rigorous implementation of work regulations on the construction of water-bearing networks, artificial water-containing objects;
- the device of high-quality waterproofing of foundations, buried structures and communications;
- arrangement of anti-filter screens under industrial water storage devices and curtains around them;
- construction of coastal, head, intercepting and other types of drainage to prevent flooding of the territory as a whole.



Fig. 2. Backfilling to increase the level of the territory

The protection against groundwater flooding of urban territories, as well as individual structures in flooded territories, is carried out mainly as follows:

- device of drains of various types;
- external or internal waterproofing of flooded buildings and structures.

Engineering protection of territories and individual structures against groundwater flooding include the following types of drainage:

- horizontal,
- vertical,
- combined,
- radiation,
- internal or special types of drainage (vacuum, electric drainage, etc.)

Internal drainage is used to protect buildings and structures when it is impossible to install classical drainage systems in the following cases:

- repair or reconstruction of the basement, when the underpinning of the foundation is not possible under the restrictions of surrounding objects (buildings, structures, roads, communications, vegetation, etc.) or if this leads to inappropriate material costs for the restoration of such objects;
- when using top-down construction methods, which do not allow installation of another type of drainage. In these cases, the joint use of internal drainage together with a waterproofing coating is possible with the further installation of humidity control systems for the premises of the underground part of the building.

Special types of drainage are used to enhance the drainage effect of poorly permeable soils (accelerate the rate of drainage, improve the performance of drainage filters). These include vacuum, electric drainage, ventilation and other drains.

Horizontal drainage is the most common type of drainage. According to the conditions for laying drains, there are two types of structures that are used in various soil conditions:

- perfect type drainage – in all aquifers without limits;
- drainages of imperfect type – in well-permeable soils (in other soils – if there is justification for the effectiveness of the application).

Vertical drainage is most effective in cases where poorly permeable soils are underlain by permeable soils with pressure waters which contribute to flooding. Combined drainage is used in cases of complex structure of the soil strata, when the upper low-permeable layer of bigger thickness is underlain by non-pressure).

Radiation drainage is used to significantly and reliably lower the level of groundwater. It is effective for drainage of territories with a complex topography and variable soil layers, in areas with dense buildings and underground space with diverse communications.

FLOODING OF TERRITORIES BY SURFACE WATERS

Flooding by surface waters is defined as an excessive rise of free surface water in a territory, as a result of an increase in the level of watercourses, reservoirs and accumulation of surface water in the lowlands.

Flooding of territories can be permanent (for example, when creating reservoirs) or temporary.

Flooding is usually marked by a temporary significant submersion of an area which is caused by natural or man-made causes and occurs mostly as a result of rising water levels in rivers, lakes and seas due to heavy rains, snow melting, seawater surge on coasts, breakthroughs of dams of natural lakes or artificial reservoirs and other reasons. Floods significantly threaten people's health which often lead to loss of lives and huge material and environmental damage.

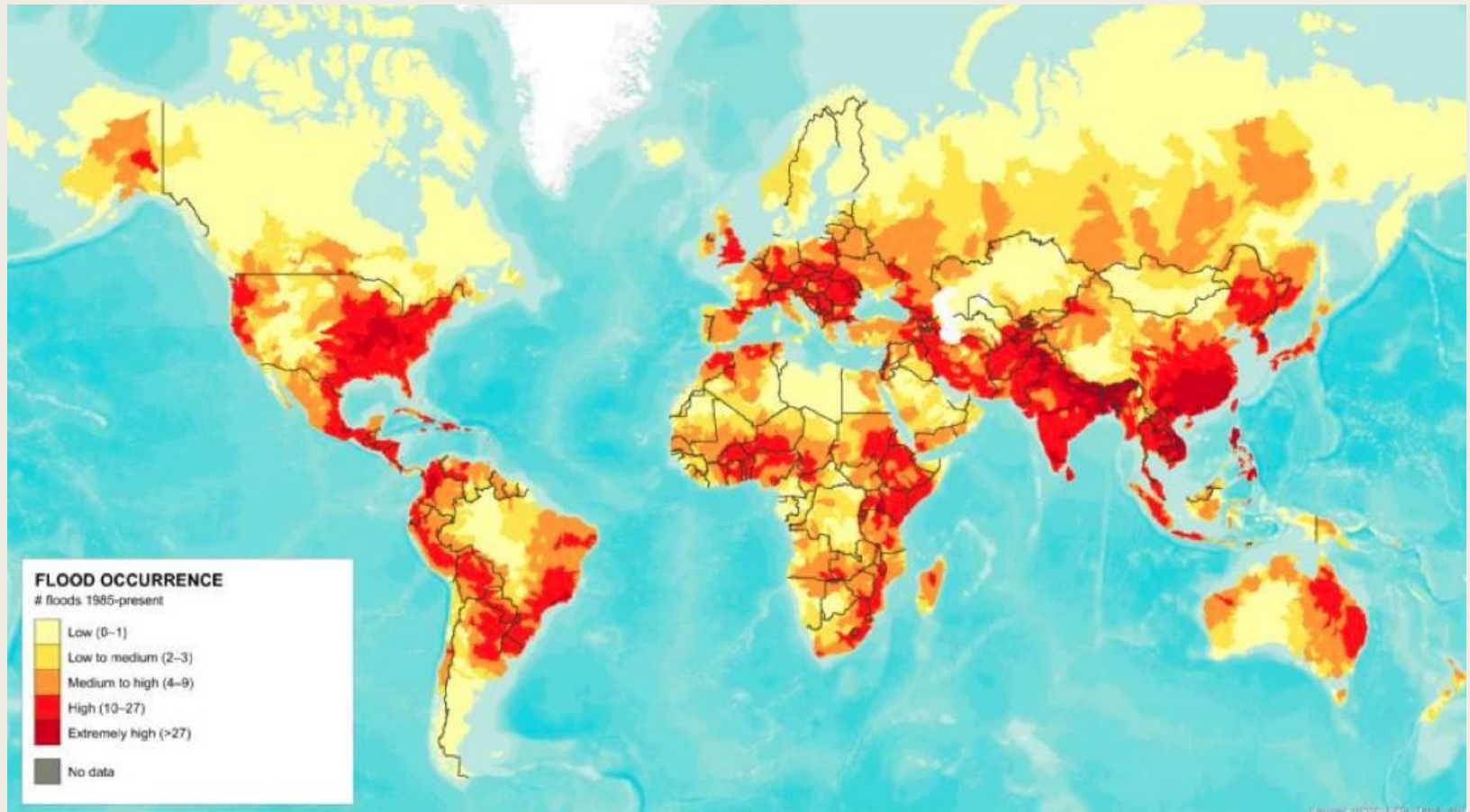


Fig. 3. Map of the likelihood of flooding (light yellow areas indicate areas with a low probability of flooding, dark red indicates a high probability)



a



b

Fig. 4. Examples of floods:
 a – flood of Burchardi, 1634;
 b – St. Petersburg, 1824;
 c – Paris, 1910;
 d – Nanjing, China, 1931;
 e – Passau, southern Germany, 2013;
 f – Port Louis after flood, 2013a



c



d



e



f

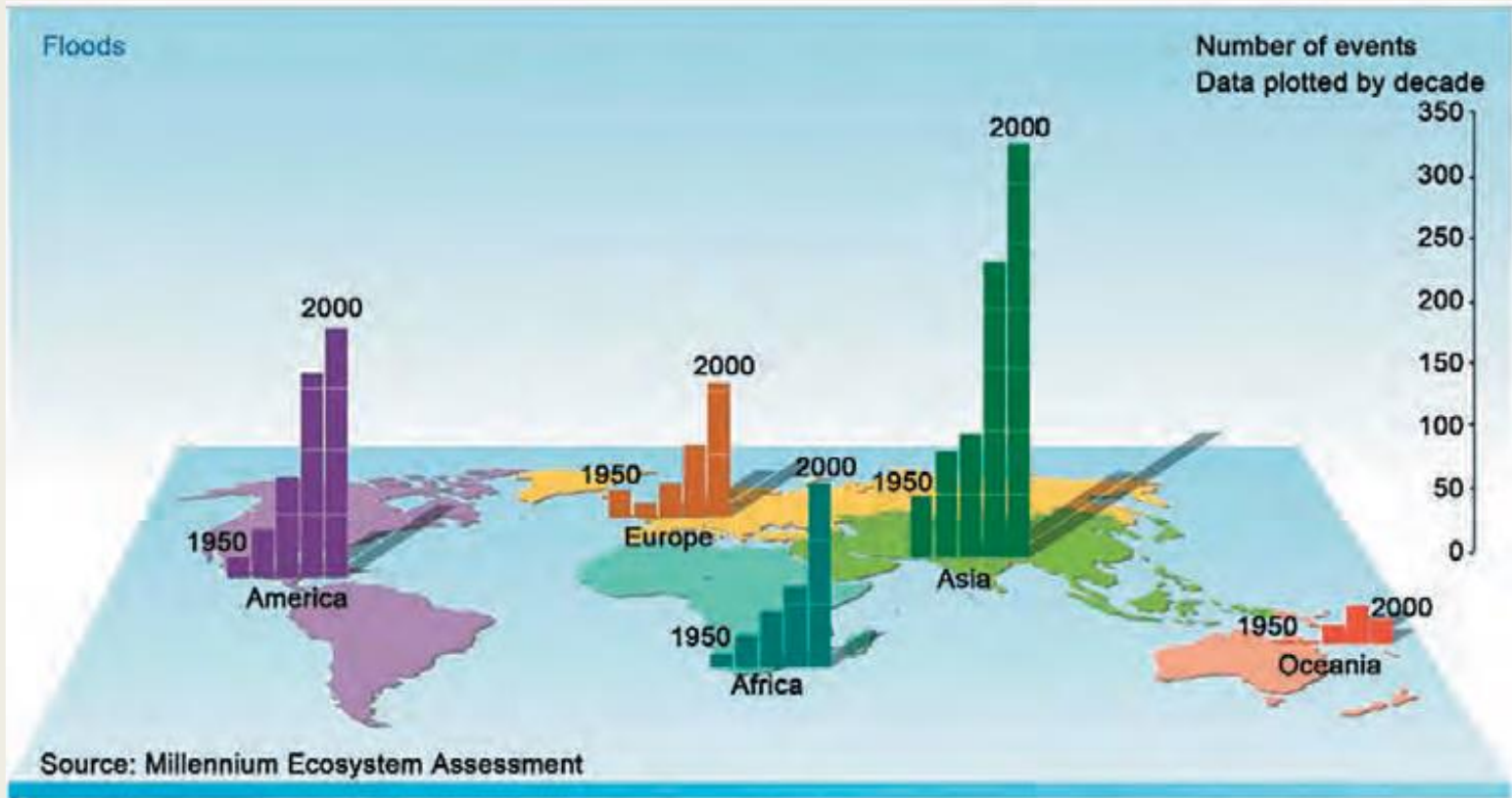


Fig. 5. Number of floods per decade from 1950 to 2000

THE MAIN TYPES AND CAUSES OF FLOODING

Among the many causes of floods, hydrologists distinguish five main types:

1. Floods associated with maximum surface runoff during spring rapid melting of the snow cover. They are classified as the greatest during the year with a rather significant rise in the water levels of rivers.

2. Floods caused by intense rains. They are characterized by a rapid, but relatively short-term rise in water levels.

3. Floods in cold climates caused by obstacles that the water stream encounters in the riverbed. This happens generally at the beginning or end of winter. With early freezing, ice in the form of sludge (loose pieces of intra-water ice and wet snow that formed in the upper river) often clogs the riverbed in narrow places, and the river overflows. Such phenomena, sometimes called glitches, at the end of winter or spring, may cause ice jamming leading to similar results.

4. Floods caused by winds on the coast of the seas or lakes on the shores of oceans, seas, large lakes and reservoirs, often in sea estuaries.

5. Floods associated with the breakthrough of dams and other hydraulic structures. When the hydraulic structure or part of it is destroyed, uncontrolled movement of large volumes of water occurs. Such floods are generally technogenic in nature.

ANTHROPOGENIC FACTORS AND CAUSES OF FLOODING

The immediate causes of anthropogenic (man-caused) floods are associated with the destruction of various dams, barrage in rivers, artificial reservoirs and various industrial reservoirs, which can occur as a result of serious emergency situations or during military operations.

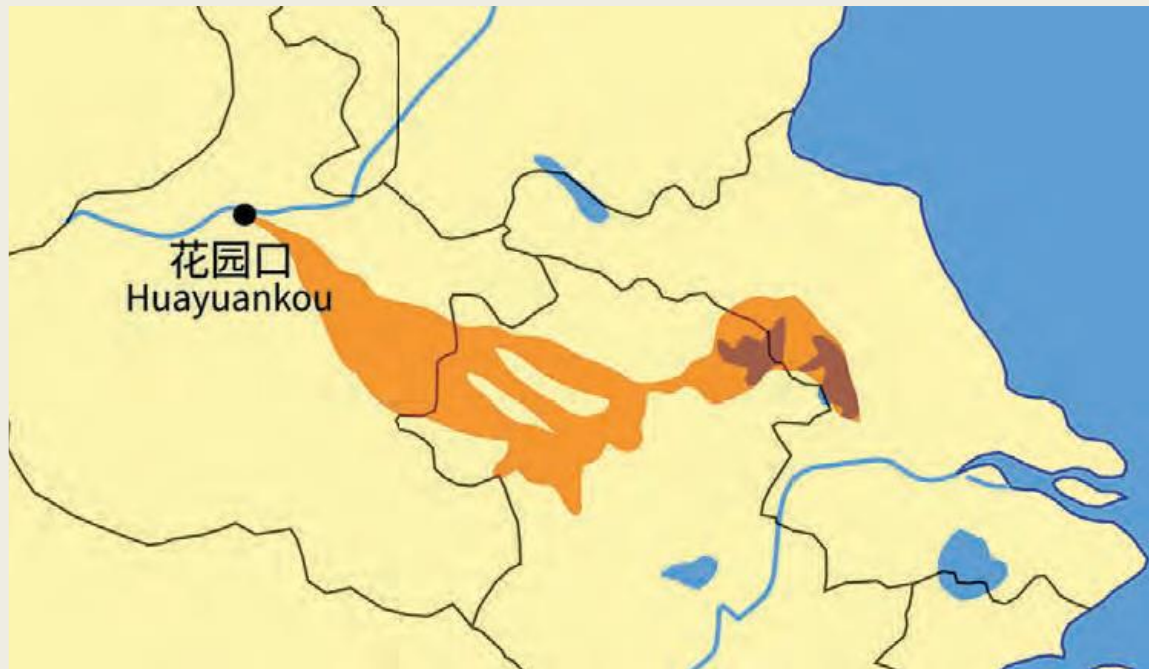


Fig. 6 Scheme of the flood zone flood on the Yellow River. By area, it approximately corresponded to the territory of entire countries, for example, the Czech Republic or Georgiahttps

In 1941, the flood caused by the demolition of part of the Dnieper hydroelectric dam in the city of Zaporozhye during the retreat of Soviet troops led to numerous civilian casualties in villages located downstream of the Dnieper



Fig. 7. Dam of the Dnieper hydroelectric station: **a** – after the explosion in 1941; **b** – 15.10.1943 г.



Fig. 8. On June 6, 2023, around 03:00 a.m., the Russian military blew up the dam of the Kakhovskaya Hydroelectric Power Station



Fig. 9 Spilling of water from the Kakhovsky Reservoir through the destroyed part of the dam of the Kakhovsky HPS. Photo of NAEK "Energoatom" from June 6, 2023.

INDIRECT CAUSES OF ANTHROPOGENIC FLOODING ARE:

- deforestation, in which the surface runoff to rivers sharply increases and water consumption during transpiration by vegetation decreases; the maximum runoff during deforestation can increase three times;
- drying of wetlands which are natural drain accumulators and this phenomenon can increase water levels by 1.3–1.6 times;
- industrial and housing development of coastal territories, which leads to a change in the hydrogeological regime of rivers due to an increase in the proportion of the surface component of runoff. There is a decrease in evaporation due to waterproof coatings (asphalt, concrete) and other developments. The presence of such coatings in an urbanized area increases floods three times compared with natural floods;
- during land preparation for agricultural purposes, the ability of soils to infiltrate water decreases and the intensity of their erosion increases;
- reducing the cross-sectional area of the flow by supports of bridge crossings, roads, dams along channels, which reduces the river output and raises the water level;
- disruption of the natural regime of flow rates and water levels, as occurs in many large rivers with seasonal regulation of flow by reservoirs. The need for electricity in the winter period increases water consumption by 2 to 3 times, which in the presence of ice cover is accompanied by an increase in water level (winter floods), which can sometimes be higher than during normal flooding.



Fig. 10. Examples of flooding of cities in Ukraine:
a – Galich, Ivano-Frankivsk region;
b – the city of Lugansk;
c – Odessaa



FLOOD PROTECTION

The main engineering structures for flood protection are flood dams, barriers for protection of populated areas, industrial and other facilities, as well as agricultural land, which should be designed and built in accordance with the requirements of existing building codes, for example DBN B.2.4-3.

Structures of engineering protection against flooding may include: embankment dams, drainage and spillway networks, drains, upland spillway channels, rapid currents and drops, pipelines and pumping stations. There are two possible approaches to protect flooded territories; common for the entire territory and for individual sites.

It is advisable to apply the general delineation of the territory if there are no watercourses on the protected territory or when the flow of existing watercourses can be transferred to reservoirs or a river through a diversion channel, pipeline or using a pump station.

The following should be considered when choosing options for structures of the embankment dams:

- topographic, engineering-geological, hydrogeological, hydrological, climatic conditions in the construction area;
- cost indicators of the structures of protective structures;
- the capacity of water discharge during floods and rain floods;
- the population density of developments of territories and the size of exclusion zones, requiring removal of buildings from flood zones;
- the feasibility of using local building materials, construction machines and mechanisms;
- the timing of the construction of facilities and ease of operation;
- environmental requirements.

DAMS

To protect territories from flooding, two types of dams are used – *non-flooded and flooded*.

Non-flooded dams are used for permanent protection against flooding of housing and industrial territories adjacent to reservoirs, rivers and other water bodies. *Flooded dams* can be used for temporary protection against flooding of agricultural lands during the cultivation of agricultural crops on them, while maintaining a normal retaining level (NPU) in the reservoir, for the formation and stabilization of riverbeds and river banks, regulation and redistribution of water flows and surface runoff.

In river sections with a meander type of channel process, the following structures for channel regulation should be included as part of engineering measures to protect territories from flooding:

- longitudinal dams, limiting the width of the river's water flow to the required design value;
- directing dams – longitudinal, rectilinear or curvilinear, providing a smooth approach of the flow to the culverts of bridges, dams, water inlets and other hydraulic structures;

- dams (dams) that block the channel from coast to coast, designed to block the flow of water in the arms and channels (Fig. 11);
- half-dams – transverse structures in riverbeds and in floodplains, providing straightening of channels and protection of coasts, as well as formation of navigable depths;
- spurs (short half-dams), installed at a certain angle to the direction of flow to ensure protection of the banks from erosion;
- coastal embankment dams, which protect coasts and dams from erosion by the current and waves;
- through structures that are being built to regulate the channel and sediment runoff through the redistribution of water flow along the channel width and the creation of a slow (non-erosion) flow rate off the coast. In the case of a significant length of dams along the watercourse or in the zone of pinching out of the reservoir, the ridge mark is reduced in the direction of flow in accordance with the longitudinal slope of the free surface of the water at the calculated level.



Fig. 11. New Croton Dam, built between 1892 and 1906 across the Croton River on the Hudson River, 35 km north of New York, USA[https](https://www.flickr.com/photos/nytimes/10101010101/)

DITCHES

Upland ditches are used to intercept the surface runoff that enters the protected area from the catchment located higher in elevation. The dimensions of the cross section and the slopes of the uphill ditches are determined by hydraulic calculation with the condition that the estimated water velocity should be less than the allowable erosion and greater than that which leads to siltation of the watercourse. The slope coefficient and the roughness coefficients of the bottom of the uphill ditches should be taken in accordance with construction standards for reclamation canals. The slopes of the uphill ditches without fixing the bottom and slopes should ensure the passage of the minimum flow rates at a speed not exceeding 0.3–0.5 m/s. The largest permissible longitudinal slopes of uphill ditches without fastening are 0.005. The minimum radius of curvature of the uphill ditch should be at least twice the width of the ditch along the water edge at the estimated flow rate. The permissible non-erosive water velocity for upland ditches with flow rates of more than 50 m³/s is adopted on the basis of research and calculations. Mountain ditches up to 5 m deep and water flow rates up to 50 m³/s, as well as aqueducts, should be designed in accordance with the requirements of building standards for drainage canals (DBN V.2.4-1).

PUMPING STATIONS AND AUXILIARY FACILITIES

The composition, layout and design of the construction of pumping stations are set depending on the volume of pumped water and the possibilities of creating storage tanks.

Types, classes of consequences (responsibility) and power of the equipment of pumping stations are determined in compliance with the requirements of prevailing standards, and also:

- estimated flow rate, feed height and fluctuations in water horizons;
- type of energy source;
- ensuring the optimal efficiency of pumps, the type and quantity of which are determined by calculation depending on the type of pumping station, taking into account the values of the calculated flow rate and water pressure and the amplitude of the horizon fluctuations in the lower and upper pools.

ENVIRONMENTAL PROTECTION

As part of engineering protection projects against flooding, the section “Organization of an observational hydraulic regime network” is required.

This section is compiled in accordance with the technical conditions issued by a specialized organization in a given area in accordance with the norms on territorial activities in construction (DBN A.2.3-1). The technical conditions consider the requirements for the arrangement of observation wells and the organization that will conduct the monitoring.

The hydraulic mode network is designed to perform monitoring of groundwater in the zone of influence of engineering protection facilities and monitoring the effectiveness of the facilities.

The section “Environmental Impact Assessment” (EIA) as part of engineering protection projects for territories and structures from flooding must strictly be respected.