River and canal engineering

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1. Scope

The term **river and canal engineering** covers all **building works** that cause a **radical change in the natural water-balance conditions in or along watercourses**, or in a **region affected by new canal building**.

River engineering embraces all **hydraulic engineering work** undertaken for the purposes of

- river straightening,
- flood protection,
- changing the use to which a watercourse is put,
- improving navigability, and
- channelising natural watercourses.

Canal engineering covers **operations** such as the building of

- artificial waterways (inland waterways and canals),
- large supply and discharge canals such as relief or irrigation canals,
- large canals for sea-going vessels (e.g. the Panama or Suez Canal), and
- artificial approaches to inland ports.

Though this varies with the size of the river, **engineering works on rivers** are generally **multi-purpose**, i.e. are intended to meet a variety of requirements such as **navigation**, **power generation**, **irrigation** and **water supply**, **flood protection**, and **maintenance** of or **change** to existing **groundwater levels** in river plains.

Though **canals** are likewise built for **navigation** and **power generation**, they also serve **supply** and **discharge** purposes (an example of a large supply canal is the Bahr el Youssef canal supplying the Fayum oasis in Egypt). **River and canal engineering** can thus perform both productive and protective functions.

In **canals**, the **water level** is usually held **constant**, or is varied only within specific preset limits. This being the case, canals are, with a few exceptions, **"zones of dormant water"** rather than **"watercourses"**. **Losses through percolation and evaporation** are inevitable and because of this canals often need an **artificial "feed"** (e.g. the Eder dam reservoir in Germany feeds the Mittelland canal).

Where in certain stretches the **water level in canals** is **above the natural lay of the land**, or where the canals run **along a slope**, particularly close attention must be paid to ensuring that the canals are **watertight** and the ground is **secure against shear failure**, to **prevent** the **risk of flooding.**

2. Environmental impacts and protective measures

2.1 Overview

River and canal works have an impact on the **whole of the environment**.

As well as the direct impacts, there will also be **indirect** or **secondary impacts** outside the area affected by the building operations proper.

This will for example be the case with **building works in the upper reaches** of large rivers, which may have direct and/or indirect **impacts down to the estuaries of the rivers** and out to the **landscape regions** that are **affected** by the river **via aquifers**. **Changes in flow velocity** for example may under certain circumstances have an adverse effect on the **oxygen balance** of a watercourse and thus on its **self-cleansing action** produced by micro-organisms. These micro-organisms are a primary food for a wide variety of flora and fauna and the latter in turn for higher lifeforms (the food chain).

2.2 River engineering operations

2.2.1 Objectives of river engineering operations

River engineering operations are generally undertaken for economic reasons and they are subject to highly complex **requirements** in respect of the **impacts** being aimed for and those that have to be taken into account. For example, **changes to wetlands or floodplains caused by river engineering** lead to changes in the **flora** and **fauna** living in these areas and to the **living conditions for different species**. Such changes may offer major benefits locally, e.g. for utilisation and the human population, but they are **acceptable** only so long as **displaced species** and flora and fauna will find **adequate living conditions** in **neighbouring regions** and a wide **diversity of species** will be **maintained**.

Hence river and canal engineering operations are normally subject to a **conflict of uses** and must therefore be planned and executed with due allowance for the widest possible **balance of interests**.

Identical or **similar river engineering operations** can be carried out for **different purposes** and for this reason the impact **descriptions** given below are classified under headings **relating** to broadly defined **engineering operations and works**.

2.2.2 Impacts from dredging operations

Dredging operations (momentary or repeated dredging operations to obtain or maintain given depths of water) have an impact on the **natural environment** firstly because of the resulting **change in the longitudinal or cross-sectional profile of the river**, which normally causes a change in its flow regime, and secondly as a result of **changes in the surroundings of the river** if the **dredged material** is going to be **deposited away from the river bed**. There may also be **changes in the groundwater level** if any permanent changes are caused to strata lying at this level.

Changes in the flow regime of a river, such as an acceleration of discharge in its middle reaches, may create a **risk of flooding** in its lower reaches. If a cut is made into certain soil formations, dredging may trigger off **erosion phenomena** whose action counteracts that of the dredging.

Depending on its consistency, **dredged material** pumped out or deposited by the side of the river may causes **changes in the flora and fauna** and in the **natural landforms**. Contaminated dredged material (which may be caused by pollution in the river water and thus in the sediments being dredged out) may in some cases have to be taken to **special dumps**, where care must be taken to protect the groundwater.

Improperly dumped dredged material, and especially contaminated material, may have detrimental impacts in the **human sphere** via **changes to flora** and fauna.

2.2.3 Transverse dykes and training structures

The purpose for which transverse dykes and training structures are intended is normally the **artificial creation of given discharge channel cross-sections** or a **given longitudinal profile** with the aim of maintaining certain **flow velocities**, **directions of flow** and **depths of water** at **low or medium flow**.

Transverse dykes and training structures have an impact on the **natural flow regime** of a river in that, where there are resulting changes in the groundwater level, they create a **risk of erosion**. They also have an impact on the **floodplain region of a river** (**waterlogging** or **desiccation damage** with the respective impacts these have on the flora and fauna; natural river-bank areas that would otherwise be diversified generally change for the worse).

Generally speaking, they are an **ideal means** of obtaining **navigable depths of water** and **given directions of flow** with as **few detrimental environmental impacts** as possible. The **construction of transverse dykes and training structures** often has the effect of making other river engineering operations, e.g. **dredging**, **unnecessary**.

2.2.4 Revetments

Revetment operations are often carried out **upstream or downstream of weirs, weirs with locks, and locks** for **hydrodynamic reasons** (as also is bed stabilisation in some cases), their purpose being to **stop erosion and scouring processes**. The revetments are generally composed of **dumped stone (rip-rap)**, which is laid on geo-textiles (as a bedding) to prevent undermining and underwashing. In special cases they may consist of **bituminous coatings** or **interlocked revetments**.

It is mainly the impermeable **bituminous or interlocked revetments** that have an impact on the natural environment in that they partly **interrupt the exchange between flowing water and ground water**. These **impacts** can however be **classified as slight** because the exchange through the bed of the river continues to operate.

Where there are **major impacts** is on the **flora and fauna living on the margins of the river banks**, because they are generally **displaced**. **Heavy bank revetment** may for example cause **spawning grounds** for fish or species of frogs and toads **to be lost**. A river confined by revetments often has a disagreeable impact on human beings due to its **unnatural appearance**. The **beneficial impacts** however, such as the reduced risk of bank collapses and erosion, promote **safe living conditions on the banks**.

2.2.5 Embankments

Embankments are built to provide **protection against flooding**.

Embankments have an impact on the natural environment firstly by **preventing the flooding** of extensive, and possibly settled, floodplains and secondly by affecting the **regime of the river at times of high water discharge**. The **absence of flooding**, of for example agricultural land on a floodplain, may sometimes cause major **changes in the moisture content of soil**, and there will be **no "fertilizing" action** of the kind produced by suspended materials deposited after floods (which action may have to be compensated for artificially where necessary). Both the above impacts give rise to further impacts on the flora and fauna of a floodplain.

Embanked stretches of a river affect **surges of flood discharge** in the same way as stretches of a canal and cause **accelerated discharge**, the possibility of **bed erosion**, and a **risk of flooding** in unprotected areas along the lower reaches of the river.

Embankments also act as **barriers to the natural surface runoff** from the floodplain into the river. On the **lower reaches of a river close to the sea** (where embankments are usually essential to deal with storm tides), the **land behind the embankment** therefore has to be **artificially drained**.

Embankments have a crucial impact on terrestrial and aquatic flora and fauna. The **change in the water balance** for example causes **changes in the habitats available to animal life of all kinds and plants**. The fast discharge in the embanked channel that occurs at times of **flood precipitation** will be particularly **destructive of spawning and breeding grounds located in areas of dormant water.**

The adverse impacts of embankments, such as high discharge velocities and the possibility of river bed and bank erosion, may also have **indirect detrimental effects on navigation and fishing**.

Agriculture in the areas protected by embankments will suffer considerable **deprivation** due to the above-mentioned **change in soil moisture content** and to the **absence of alluvial loam**.

Embankments hamper free access to watercourses and need to be **scrupulously managed** and **maintained** to prevent any risk of breaches occurring in them.

Where in special cases **embankments** are revetted with stone or bituminous materials to protect them against wash or wave action, they also **disfigure** the **landscape**.

2.2.6 Bottom sills, step sills, weirs (alone or in combination with locks or run-of-river hydroelectric stations)

Bottom sills, step sills and weirs are generally built to **improve navigation** and **exploit water power**, but they are also built for **reasons connected with water management**.

To **control water levels and discharge**, **weirs** can be designed to be either **fixed or with adjustable spillways or sluices**. At the same time, weirs are also built in association with locks and/or hydroelectric stations or in association with abstracting structures to divert water into other channels (generally for irrigation).

Low **bottom sills or step sills** produce small to medium changes in the flow gradient. All the **impacts generated by such structures** are **proportional to their size** and to make things simpler the following description is confined to weirs but the impacts of bottom sills and step sills can be inferred from what is said:

Weirs constitute a **major interference** with the **discharge regime** of a river and they **divide** the river into an **upstream section** and a **downstream section** which are precisely separated by the structure itself. This causes a **break in the transport of bed load and sediment**. The division into two, combined with the raising of the water level in the **upstream section**, will cause **sedimentation** to occur in this section; in the **downstream section**, the greater tractive force of the water, which is free of sediment, will **increase sediment uptake**, or in other words there will be **pronounced erosion from the river bed and banks**.

In the **upstream section**, the rise in the water level will cause a **change in the groundwater level in the foreshore** back to the point where the incoming flow joins the water at the higher level. Because of the rise in the water level, **embanking** of the foreshore will often be necessary to **stop flooding** at times of flood discharge (see "Embankments").

Due to the **change in flow velocity** in the upstream section, the **river's self-cleaning action** will be **seriously affected** and this will lead to a **deterioration in water quality** that will be particularly pronounced during low water periods.

The **raising of the groundwater level** will have considerable **effects** on the **terrestrial flora and fauna**:

- The division of the river into two will **hamper** the **natural migration** of fish (there is a limit to how far fish ladders are able to solve this problem);
- **Spawning grounds** may become difficult or impossible to reach, and as a result **certain species** may **die out** or **stay away**;
- As a result of the **reduction in flow velocity** upstream of the weir

• **water plants** may **proliferate** again;
• **breeding grounds for anopheles mosquitoes and insects** may arise in areas of dormant water;
• snails which act as intermediate hosts for **bilharzia** (schistosomiasis) may take up residence on the banks, thus helping to spread the disease;
• there will be impacts on the aquatic flora and fauna as a result of the **deterioration in water quality** mentioned above (caused by the oxygen;
• there may be **detrimental effects** on **fishing**;
• **special measures** may in certain cases have to be taken to provide **flood protection** because the weir contracts the cross-section of the channel and the level of the water impounded upstream rises above the original flood mark;
• to **combat** the **risk of erosion** in the area downstream of a weir, **sediment and bed load** may have to be added to the flow **artificially**.

For the **population**, the direct **impacts** that occur will generally be **beneficial** (**safety from flooding**, a **supply of water and power**). **Detrimental impacts** have to do with **changes to the landscape** and the **health of the population**. The latter may be adversely affected by the **spread of disease vectors**. When this is the case, action should be taken in good time to **inform** the population and **make them more aware**, particularly **women**, who have traditionally been **responsible for water and matters of hygiene**.

2.2.7 River straightening or channelisation

The **straightening of rivers** is carried out for a variety of purposes and may be done for **reasons of water management** or on **use-related grounds**.

The impacts of **straightening or channelisation** vary with the way in which the operation is carried out. A distinction can be made between the following **operations**:

- **cutting off a loop of the river** while **preserving the loop as a cut off arm** (a body of dormant or flowing water serving to drain off flood water or for other purposes). The operation is performed for the purposes of power generation (to increase head) and/or to improve navigability.
- straightening and shifting the course of the river without preserving the old bed. A water management operation for flood protection purposes or the like.

Cutting off as defined above normally breaks down into the following **parts**:

the cut, the cut off arm, weir structures in the cut off arm and the cut to raise the water level upstream, and building of a lock associated with one of the weirs or construction of one of the weirs as part of a hydroelectric generator station.

Channelisation is generally a **hybrid** undertaking consisting of **river straightening** (cutting off) and **lining** of the natural bed to create a **uniform channel cross-section** (in the interests of navigability). The **impacts of channelisation** will be dealt with in the **section on canal engineering.**

2.2.7.1 Cut-offs

A **cut-off** will **alter the flow regime of the river**. The **shortening of the distance flowed** produces an **increase in the bed gradient** and a **rise in flow velocity** in the cut.

Without weirs the **cut off arm would dry up**. The rise in flow velocity may cause a drop in water level **upstream of the cut**, **heavier erosion** of the river bed (upstream and in the cut), and **sedimentation downstream**. The high water peaks become higher and produce a greater **risk of flooding** in **downstream areas.**

Groundwater levels will be adversely affected upstream of and in the area where the operation is carried out. In the long term there will be a **lowering of the groundwater level**. As an example, the Jongley canal (a cut-off on the White Nile from Malakal to Juba) was built a) to shorten the length of the journey by boat and b) to increase the average daily discharge by 40 x 10 m^3 (approx. 460 m^3/s) by draining the marshes south of Malakal.

When there are **weir structures** (a weir with or without a lock in the cut and a hydroelectric generator station situated on the cut off arm, or vice versa, or the cut off arm blocked off underwater and all the structures situated in the cut), they produce the **impacts described above under "weirs" in the areas upstream and downstream**.

In the region of the cut, the **impacts** depend **on the groundwater conditions** in the environs of the **location of the structure** (at the upstream or downstream end of the cut).

In the **cut off arm**, there may be **changes in water quality** if nothing is done to ensure circulation by providing a link with the main watercourse (e.g. there may be eutrophication = a change in balance in the body of water due to heavy enrichment with nutrients, excessive algal growth, and severe oxygen deficiency).

Cuts without weirs have a **pronounced effect on the flora and fauna** in and in the environs of the former river bed (the cut off arm). Here, the **change in groundwater levels** (the channel acts as a drain) will certainly **have an adverse effect** on the **flora**, and the old **riparian vegetation** whose growth is controlled by areas of moisture will **die out**. As a result the possibility of **adverse impacts on the fauna** cannot be ruled out.

In the case of **cuts with weirs**, there are **impacts similar to those from weirs** in the upstream and downstream areas. In the **region of the cut off arm**, there are **additional** adverse impacts that can be anticipated:

- When the cut off arm is made dormant, the water in it may undergo **eutrophication**. In tropical regions, water hyacinths may **overgrow the entire surface of the water**, with corresponding adverse effects on the fauna.
- Cut off arms provide the right conditions for becoming **breeding grounds for insects** and **disease vectors** (waterborne and vector-borne diseases).
- In cut off arms, there may be a **sharp rise in the fish population**, and when this is the case there will be a **change in the species represented** (fish living in flowing water move away and those living in still water become more populous).

Hydroelectric generator stations will **change the discharge regime downstream**, and as a result there will be **changes to the flora and fauna** (levelling out of discharge, peak capacity operation will cause rises and falls, etc. see the environmental brief Large-scale Hydraulic Engineering). The **running of the turbines** themselves may produce a **deathtrap** for **fish**.

Changes in water quality in the cut off arm and the breeding of waterborne and vector-borne pathogens will create a **threat to the health of the population** (see also page 11).

2.2.7.2 Straightening of watercourses

The **shortening of the path of flow** (e.g. by the straightening of meanders) causes a **rise in discharge velocity** and a result of this, **flood waves** are **dissipated more quickly**. As a **consequence**:

- the **foreshore** is **no longer immersed** or is not immersely as deeply as previously and because of this

• infiltration into the groundwater decreases and groundwater recharge is adversely affected;

- there is a change in the position of the groundwater table;
- bed and bank erosion begin to occur unless suitable bed stabilisation and bank protection are applied;
- in the estuary region or in areas where the bed gradient is shallow, embankments must be built for protection against flooding caused by peak high water discharge.

Changes in the groundwater will produce **impacts on the flora**. The **drying up of areas of marsh or swamp** will mean changes in the **diversity of plant species**.

The **fauna** will be **adversely affected** likewise; the **composition** of the **fish population** will be **altered** by the removal of spawning grounds and that of the population of other organisms by the removal of areas of still water and changes to riparian zones.

The **low risk of flooding** will have an **economically beneficial** impact on the **usefulness of the foreshore**. **Draining** may enable **economic use to be made** of areas of marsh or swamp. Entire regions may be turned over to agricultural use by constructing drainage channels and setting up pumping stations which feed into the channelised river. This will necessarily mean a change in the flora and fauna of the land involved.

The **straightening operations** will also **interfere with the appearance of the landscape**. **Riparian vegetation** which was characteristic of the landscape and peculiar to it **will disappear**.

In socio-economic terms, the impact of the operations in question will be **beneficial** in that there will be **fewer floods** and **less damage** of various kinds.

2.3 Canal engineering

The **building of canals and navigable waterways** is generally carried out for **economic reasons** to provide a **cheap mode of transport** or to **divert watercourses** or **lift them over obstacles**.

When serving as **links between seas and/or river systems**, **canals** often run through regions in which there would not normally be any great abundance of surface water. To overcome **differences in elevation**, **locks** and **boat lifts** have to be constructed. **Artificial waterways** of this kind have to be **fed with water** because evaporation, seepage, locking operations, etc. cause **water losses** and the water in the canal has to be kept at a certain level for proper navigation or for the sake of other users.

This being the case, **impacts** arise from the **supply of water to the canal**, where the water used is impounded water, and from the routing of the canal.

Canals have impacts on the **water balance over a large area**. For example:

- the **groundwater level** may undergo **changes** because canals act as giant drainage channels;
- **water quality** may **deteriorate** due to the discharge of wastewater and solid waste by vessels.

In addition to this, the change in the water balance may also occasion **local changes in microclimate**, which in turn will have secondary impacts.

Breaches in raised sections of canals may cause **considerable damage to the canal itself and in surrounding areas**.

The **changes in the water balance in the region** will have **consequences for the terrestrial flora and fauna**. **Certain species of plants** may be **totally destroyed**, i.e. wet biotopes and their flora may be destroyed if, for example, the supply of water for the canal is obtained by draining areas of marshland. Canals also cut across the **natural migration routes** of game and small animals and may **fragment habitats**.

Dried wetlands will undergo a **change of use**, i.e. they will be converted into farmland or forest land.

It is possible that there may also be adverse impacts, particularly on the **landscape due to the routing** of the canal and due to the structures required such as embankments, locks, boat lifts, aqueducts and road bridges.

As well as this, there is also a considerable **risk to humans and animals in the event of** breaches in the banks or bed of the canal in raised sections or on aqueducts.

A **canal** will **cut across traditional connecting routes and channels of communication**. **Bridges** will need to be built to allow roads and footways to cross the canal, but it will be found that the **problems** created by divisions of this kind are **not amenable to a total cure**. On the other hand, canals may have a high **leisure amenity value** for **watersports**.

3. Notes on the analysis and evaluation of environmental impacts

Specifically in the case of rivers it should be remembered that, generally speaking, **impacts** may arise along their entire course. Due to the **water supply** that they require, **canals** too have **wide-ranging impacts**.

What will give trouble when evaluating the environmental impacts in this case is the question of quantifying the impacts. Qualitative descriptions are one option but to allow others to appreciate all the implications of what is being said they should be as detailed as possible.

Due to the **complex interrelationships** involved and current **ignorance** as to the real causal factors that contribute to an impact (it is only seldom that a single factor is responsible for an impact), the possibility of misinterpretations cannot be ruled out. In this case a useful method of arriving at genuinely relevant conclusions may be to make a comparison with the **impacts**

generated by existing river and canal engineering operations in similar situations, climates, topographical conditions etc. However, when doing so it is important to **identify factors that are relevant** to the impacts in the particular environmental areas and to **bring out** the **relationships** that exist between the action taken and its impact. **Particular importance** should be attached to the questions of **species protection**, **changes in biotopes** and **maximum permitted changes in groundwater levels**.

4. Interaction with other sectors

The closest **points of contact** that river and canal engineering operations have are with sectors that generate an additional **demand for water**. Existing water rights will need to be taken into account in this case.

The main sector that should be mentioned is **agriculture**, because this is affected by all river and canal engineering projects either because it makes use of the same resource for irrigation purposes or because there is a change in the use of land or because terrestrial fauna are affected or because there are added secondary impacts.

Mention should also be made of the **supply of water**. Water supply, which is one of the priority concerns for developing an area, must always be covered in the planning for all projects in all sectors and the demands it makes should always be considered as a matter of priority.

Aspects of **rural hydraulic engineering** and **large-scale hydraulic engineering** projects and port and harbour construction projects often have a bearing on river and canal engineering.

In this connection, the reader is referred to the relevant environmental briefs Rural and Large-scale Hydraulic Engineering, Water Supply, etc. and the environmental briefs of more general ambit on planning should also be consulted.

5. Summary assessment of environmental relevance

In **principle**, it is perfectly **feasible** for river and canal engineering projects to be **planned and executed with only minor environmental impacts**. **Planning procedures** and the **engineering means** both **exist**. However, all over the world there has been **experience of adverse effects** on the environment. The reason for this was that in planning and executing river and canal engineering works it was only the purpose, such as water power, irrigation, flood protection, protection of drinking water, or navigation and handling of goods, that was considered, or in other words attention was only paid to the use aspect, and the impacts the projects would have on the natural environment and in the human sphere, with all the problems of settlement/resettlement and changes in socio-economic and socio-cultural conditions, were either totally ignored or given only cursory scrutiny.

When major projects for making rivers navigable or for building canals (which fragment the landscape) are mooted, **sex-specific and group-specific socio-economic analyses** should be carried out to see how far specific groups within the society will be affected by the adverse effects of carrying out the project or can share in its expected benefits. Hydraulic engineering operations have a particularly marked effect on women.

River and canal engineering operations should always be planned and executed in such a way as to minimise the **risk to the environment** posed by the planning and building. By **careful analysis** of all the impacts and by making corrections at the planning stage it will be possible to keep the **consequences** of man's interference with the ecosystem and with the human environment within **acceptable** bounds. The presence of human beings and the needs these human beings have are factors that must be accorded an essential place in the planning.

This should be achieved by means of **participatory decision-making processes** that provide the **persons affected** with an **opportunity to assert their justified interests and desires** at all stages of the planning and execution of a project.

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