SSIGL 11

NATIONAL GUIDELINES

For Small Scale Irrigation Development in Ethiopia

Free River Side Intake Study and Design

November 2018

Addis Ababa

MINISTRY OF AGRICULTURE

National Guidelines for Small Scale Irrigation Development in Ethiopia

SSIGL 11: Free River Side Intake Study and Design

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First Edition 2018

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FORWARD

Ministry of Agriculture, based on the national strategic directions is striving to meet its commitments in which modernizing agriculture is on top of its highest priorities to sustain the rapid, broad-based and fair economic growth and development of the country. To date, major efforts have been made to remodel several important strategies and national guidelines by its major programs and projects.

While efforts have been made to create access to irrigation water and promoting sustainable irrigation development, several barriers are still hindering the implementation process and the performance of the schemes. The major technical constrains starts from poor planning and identification, study, design, construction, operation, and maintenance. One of the main reasons behind this outstanding challenge, in addition to the capacity limitations, is that SSIPs have been studied and designed using many ad-hoc procedures and technical guidelines developed by various local and international institutions.

Despite having several guidelines and manuals developed by different entities such as MoA (IDD)-1986, ESRDF-1997, MoWIE-2002 and JICA/OIDA-2014, still the irrigation professionals follow their own public sources and expertise to fill some important gaps. A number of disparities, constraints and outstanding issues in the study and design procedures, criteria and assumptions have been causing huge variations in all vital aspects of SSI study, design and implementation from region to region and among professionals within the same region and institutions due mainly to the lack of agreed standard technical guidelines. Hence, the SSI Directorate with AGP financial support, led by Generation consultant (GIRDC) and with active involvement of national and regional stakeholders and international development partners, these new and comprehensive national guidelines have been developed.

The SSID guidelines have been developed by addressing all key features in a comprehensive and participatory manner at all levels. The guidelines are believed to be responsive to the prevalent study and design contentious issues; and efforts have been made to make the guidelines simple, flexible and adaptable to almost all regional contexts including concerned partner institution interests. The outlines of the guidelines cover all aspects of irrigation development including project initiation, planning, organizations, site identification and prioritization, feasibility studies and detail designs, contract administration and management, scheme operation, maintenance and management.

Enforceability, standardization, social and environmental safeguard mechanisms are well mainstreamed in the guidelines, hence they shall be used as a guiding framework for engineers and other experts engaged in all SSI development phases. The views and actual procedures of all relevant diverse government bodies, research and higher learning institutions, private companies and development partners has been immensely and thoroughly considered to ensure that all stakeholders are aligned and can work together towards a common goal. Appropriately, the guidelines will be familiarized to the entire stakeholders working in the irrigation development. Besides, significant number of experts in the corresponding subject matter will be effectively trained nationwide; and the guidelines will be tested practically on actual new and developing projects for due consideration of possible improvement. Hence, hereinafter, all involved stakeholders including government & non-governmental organizations, development partners, enterprises, institutions, consultants and individuals in Ethiopia have to adhere to these comprehensive national guidelines in all cases and at all level whilst if any overlooked components are found, it should be documented and communicated to MOA to bring them up-to-date.

Therefore, I congratulate all parties involved in the success of this effort, and urge partners and stakeholders to show a similar level of engagement in the implementation and stick to the guidelines over the coming years.

H.E. Dr. Kaba Urgessa
State Minister, Ministry of Agriculture

SMALL SCALE IRRIGATION DEVELOPMENT VISION

Transforming agricultural production from its dependence on rain-fed practices by creating reliable irrigation system in which smallholder farmers have access to at least one option of water source to increase production and productivity as well as enhance resilience to climate change and thereby ensure food security, maintain increasing income and sustain economic growth.

ACKNOWLEDGEMENTS

The preparation of SSIGLs required extensive inputs from all stakeholders and development partners. Accordingly many professionals from government and development partners have contributed to the realization of the guidelines. To this end MOA would like to extend sincere acknowledgement to all institutions and individuals who have been involved in the review of these SSIGLs for their comprehensive participation, invaluable inputs and encouragement to the completion of the guidelines. There are just too many collaborators involved to name exhaustively and congratulate individually, as many experts from Federal, regional states and development partners have been involved in one way or another in the preparation of the guidelines. The contribution of all of them who actively involved in the development of these SSIGLs is gratefully acknowledged. The Ministry believes that their contributions will be truly appreciated by the users for many years to come.

The Ministry would like to extend its appreciation and gratitude to the following contributors:

- Agriculture Growth Program (AGP) of the MoA for financing the development and publication of the guidelines.
- The National Agriculture Water Management Platform (NAWMP) for overseeing, guidance and playing key supervisory and quality control roles in the overall preparation process and for the devotion of its members in reviewing and providing invaluable technical inputs to enrich the guidelines.
- Federal Government and Regional States organizations and their staff for their untiring effort in reviewing the guidelines and providing constructive suggestions, recommendations and comments.
- National and international development partners for their unreserved efforts in reviewing the guidelines and providing constructive comments which invaluably improved the quality of the guidelines.
- Small-scale and Micro Irrigation Support Project (SMIS) and its team for making all efforts to have quality GLs developed as envisioned by the Ministry.

The MOA would also like to extend its high gratitude and sincere thanks to AGP’s multi development partners including the International Development Association (IDA)/World Bank, the Canada Department of Foreign Affairs, Trade and Development (DFATD), the United States Agency for International Development (USAID), the Netherlands, the European Commission (EC), the Spanish Agency for International Development (AECID), the Global Agriculture and Food Security Program (GAFSP), the Italy International Development Cooperation, the Food and Agriculture Organization (FAO) and the United Nations Development Program (UNDP).

Moreover, the Ministry would like to express its gratitude to Generation Integrated Rural Development Consultant (GIRDC) and its staff whose determined efforts to the development of these SSIGLs have been invaluable. GIRDC and its team drafted and finalized all the contents of the SSIGLs as per stakeholder suggestions, recommendations and concerns. The MoA recognizes the patience, diligence, tireless, extensive and selfless dedication of the GIRDC and its staff who made this assignment possible.

Finally, we owe courtesy to all national and International source materials cited and referred but unintentionally not cited.

Ministry of Agriculture

DEDICATIONS

The National Guidelines for Small Scale Irrigation Development are dedicated to Ethiopian smallholder farmers, agro-pastoralists, pastoralists, to equip them with appropriate irrigation technology as we envision them empowered and transformed.

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ACRONYMS

AASHO	American Association of State Highway Officials
AGP	Agricultural Growth Program
ANRS	Amhara National Regional State
B	Width of intake
FAO	Food and Agriculture Organization
GIRDC	Generation Integrated Rural Development Consultant
GTZ/GIZ	German International Development cooperation
hd	Sill height or Flow depth on the crest (as required)
HFL	High Flood Level
LSIP	Large Scale Irrigation Project
m	meter
m3/s	Cubic meter per second
MoANR	Ministry of Agriculture and Natural Resources
MOANR	Ministry of Agriculture and Natural Resource
MOWIE	Ministry of Water, Irrigation and Electricity
Q	Discharge
Qp	Design Flood for the Selected Return Period i.e. Q50 in this Manual
R	Hydraulic mean depth or scour depth or Hydraulic radius
RBL	River Bed Level
SSID	Small Scale Irrigation Development
SSIGL	Small Scale Irrigation Guideline
SSIP	Small Scale Irrigation Project
SSIS	Small Scale Irrigation Schemes
TWD	Tail Water Depth
USDA	United States Department of Agriculture
WL	Water Level

PREFACE

While irrigation development is at the top of the government's priority agendas as it is key to boost production and improve food security as well as to provide inputs for industrial development. Accordingly, irrigated land in different scales has been aggressively expanding from time to time. To this end, to enhance quality delivery of small-scale irrigation development planning, implementation and management, it has been decided to develop standard SSI guidelines that must be nationally applied. In September 2017 the Ministry of Agriculture (MoA) had entrusted Generation Integrated Rural Development Consultant (GIRDC) to prepare the National Small-scale Irrigation Development Guidelines (SSIGLs).

Preparation of the SSIGLs for enhancing development of irrigated agriculture is recognized as one of the many core initiatives of the MoA to improve its delivery system and achieve the targets in irrigated agriculture and fulfill its mission for improving agricultural productivity and production. The core objective of developing SSIGLs is to summarize present thinking, knowledge and practices to enable irrigation practitioners to properly plan, implement and manage community managed SSI schemes to develop the full irrigation potential in a sustainable manner.

As the SSIGLs are prepared based on national and international knowledge, experiences and practices, and describe current and recommended practice and set out the national standard guides and procedures for SSI development, they serve as a source of information and provide guidance. Hence, it is believed that the SSIGLs will contribute to ensuring the quality and timely delivery, operation and maintenance of SSI schemes in the country. The SSIGLs attempt to explain and illustrate the important concepts, considerations and procedures in SSI planning, implementation and management; and shall be used as a guiding framework for professionals engaged in SSI development. Illustrative examples from within the country have been added to enable the users understand the contents, methodologies presented in the SSIGLs.

The intended audiences of the SSIGLs are government organizations, NGOs, CSOs and the private sector involved in SSI development. Professionally, the SSIGLs will be beneficial for experienced and junior planners, experts, contractors, consultants, suppliers, investors, operators and managers of SSI schemes. The SSIGLs will also serve as a useful reference for academia and researchers involved and interested in SSI development. The SSIGLs will guide to ensure that; planning, implementation and management of SSI projects is formalized and set procedures and processes to be followed. As the SSIGLs provide information and guides they must be always fully considered and applied by adapting them to the local specific requirements.

In cognizance with the need for quality SSIGLs, the MoA has duly considered quality assurance and control during preparation of the guidelines. Accordingly, the outlines, contents and scope of the SSIGLs were thoroughly discussed, reviewed and modified by NAWMP members (senior professionals from public, national and international stakeholder) with key stakeholders in many consultative meetings and workshops. Moreover, at each milestone of SSIGL preparation, resource persons from all stakeholders reviewed and confirmed that SSIGLs have met the demands and expectations of users.

Moreover, the Ministry has mobilized resource persons from key Federal, National Regional States level stakeholders and international development partners for review, validation and endorsement of the SSIGLs.

Several hundreds of experienced professionals (who are very qualified experts in their respective fields) from government institutions, relevant private sector and international development partners have significantly contributed to the preparation of the SSIGLs. They have been involved in all aspects of the development of SSIGLs throughout the preparation process. The preparation process included a number of consultation meetings and workshops: (i) workshop to review inception report, (ii) workshop on findings of review of existing guidelines/manuals and proposed contents of the SSIGLs, (iii) meetings to review zero draft SSI GLs, (iv) review workshop on draft SSI GLs, (v) small group review meetings on thematic areas, (vi) small group consultation meetings on its final presentation of contents and layout, (vii) consultation mini-workshops in the National States on semi-final versions of the SSIGLs, and (viii) final write-shop for the appraisal and approval of the final versions of SSIGLs.

The deliberations, concerns, suggestions and comments received from professionals have been duly considered and incorporated by the GIRD Consultant in the final SSIGLs.

There are 34 separate guidelines which are categorized into the following five parts concurrent to SSI development phases:

Part-I. Project Initiation, Planning and Organization Guideline which deals with key considerations and procedures on planning and organization of SSI development projects.

Part-II. Site Identification and Prioritization Guideline which treats physical potential identification and prioritization of investment projects. It presents SSI site selection process and prioritization criteria.

Part-III. Feasibility Study and Detail Design Guidelines for SSID dealing with feasibility study and design concepts, approaches, considerations, requirements and procedures in the study and design of SSI systems.

Part-IV. Contract Administration and Construction Management Guidelines for SSI development presents the considerations, requirements, and procedures involved in construction of works, construction supervision and contract administration.

Part-V. SSI Scheme Management, Operation and Maintenance Guidelines which covers SSI Scheme management and operation.

Moreover, Tools for Small Scale Irrigation development are also prepared as part of SSIGLs.

It is strongly believed and expected that; the SSIGLs will be quickly applied by all stakeholders involved in SSI development and others as appropriate following the dissemination and familiarization process of the guidelines in order to ensure efficient, productive and sustainable irrigation development.

The SSIGLs are envisioned to be updated by incorporating new technologies and experiences including research findings. Therefore, any suggestions, concerns, recommendations and comments on the SSIGLs are highly appreciated and welcome for future updates as per the attached format below. Furthermore, despite efforts in making all types of editorial works, there may still errors, which similarly shall be handled in future undated versions.

UPDATING AND REVISIONS OF GUIDELINES

The GLs are intended as an up-to-date or a live document enabling revisions, to be updated periodically to incorporate improvements, when and where necessary; may be due to evolving demands, technological changes and changing policies, and regulatory frameworks. Planning, study and design of SSI development interventions is a dynamic process. Advancements in these aspects are necessary to cope up with the changing environment and advancing techniques. Also, based on observation feedbacks and experiences gained during application and implementation of the guidelines, there might be a need to update the requirements, provisions and procedures, as appropriate. Besides, day-by-day, water is becoming more and more valuable. Hence, for efficient water development, utilization and management will have to be designed, planned and constructed with a new set up of mind to keep pace with the changing needs of the time. It may, therefore, be necessary to take up the work of further revision of these GLs.

This current version of the GLs has particular reference to the prevailing conditions in Ethiopia and reflects the experience gained through activities within the sub-sector during subsequent years. This is the first version of the SSI development GLs. This version shall be used as a starting point for future update, revision and improvement. Future updating and revisions to the GLs are anticipated as part of the process of strengthening the standards for planning, study, design, construction, operation and management SSI development in the country.

Completion of the review and updating of the GLs shall be undertaken in close consultation with the federal and regional irrigation institutions and other stakeholders in the irrigation sub-sector including the contracting and consulting industry.

In summary, significant changes to criteria, procedures or any other relevant issues related to technological changes, new policies or revised laws should be incorporated into the GLs from their date of effectiveness. Other minor changes that will not significantly affect the whole nature of the GLs may be accumulated and made periodically. When changes are made and approved, new page(s) incorporating the revision, together with the revision date, will be issued and inserted into the relevant GL section.

All suggestions to improve the GLs should be made in accordance with the following procedures:

I. Users of the GLs must register on the MOA website: Website: www.moa.gov.et
II. Proposed changes should be outlined on the GLs Change Form and forwarded with a covering letter or email of its need and purpose to the Ministry.
III. Agreed changes will be approved by the Ministry on recommendation from the Small-scale Irrigation Directorate and/or other responsible government body.
IV. The release date of the new version will be notified to all registered users and authorities.

Users are kindly requested to present their concerns, suggestions, recommendations and comments for future updates including any omissions and/or obvious errors by completing the following revisions form and submitting it to the Ministry. The Ministry shall appraise such requests for revision and will determine if an update to the guide is justified and necessary; and when such updates will be published. Revisions may take the form of replacement or additional pages. Upon receipt, revision pages are to be incorporated in the GLs and all superseded pages removed.

Suggested Revisions Request Form (Official Letter or Email)

To: --
From: ---
Date: --
Description of suggested updates/changes: Include GL code and title, section title and # (heading/subheading #), and page #.

GL Code and Title	Date	Sections/ Heading/Subheading/ Pages/Table/Figure	Explanation	Comments (proposed change)

Note that be specific and include suggested language if possible and include additional sheets for comments, reference materials, charts or graphics.

GLs Change Action

Suggested Change	Recommended Action	Authorized by	Date

Director for SSI Directorate: ________________________**Date:** _________________

The following table helps to track initial issuance of the guidelines and subsequent Updates/Versions and Revisions (Registration of Amendments/Updates).

Revision Register

Version/Issue/Revision No	Reference/Revised Sections/Pages/topics	Description of revision (Comments)	Authorized by	Date

1 INTRODUCTION

1.1 OBJECTIVE AND SCOPE OF THE GUIDELINE

The objective of this guideline, for Design of Free River Intake Structure, is aims to provide well organized and comprehensive user friendly material tailored with the current design practice being exercised in our country.

As the purpose of the Guideline is for the aid of small scale irrigation scheme design, the scope is also limited to the design of Free River Side Intake in Small Scale irrigation Schemes. The guideline is thus prepared to assist practicing engineers to get easily in to the hydraulic and structural design aspects with the aid of basic concept, demonstration, worked example and supplemented with design aid templates.

1.2 DEFINITIONS OF TECHNICAL TERMINOLOGIES

Abutment: That part of a valley side against which the structure is constructed. Artificial abutments are sometimes constructed to take the thrust of an arch where there is no suitable natural abutment.

Bed bar: is a structure used for stabilizing bed of a river along its axis.

Cross-section: is a hypothetical section line which defines the shape of a channel, stream, or valley as viewed across its axis. In watershed investigations it is determined by a line approximately perpendicular to the main path of water flow, along which measurements of distance and elevation are taken to define the cross-sectional area;

Design discharge or flow: Is the rate of flow for which a hydraulic facility (wing-wall) is designed and thus expected to accommodate without exceeding the adopted design constraints. It is also called design flood and is defined as maximum flood selected/desired for certain return period that any structure can safely pass.

Freeboard: The vertical distance between the level of the water surface, usually corresponding to design flow and a point of interest such as top of a wing-wall or specific location on the roadway grade.

Head: is the difference in water level between two reference points & is thus energy required to drive water from higher point to the lower point (for gravity flow).

Headwork: is any hydraulic structure located across the stream or on the lake, reservoir and/or ground water to collect reserve or divert water for irrigating crops and/or hydropower use. Thus it includes Diversion Headwork/Weir, Free Intake structure, Pump, Spring Protection or Development, Dam and Ground water extraction. In a storage system, such structure is called a 'Storage dam' and the main body of the structure is mostly 'Earth-dam' where-as for a diversion system, it is called a 'Weir', and the water pool is called a 'Pond'.

Intake structure: It is also called a head regulator structure and situated at the upstream end of a headwork consisting of a chamber, trash-rack, gate and sometimes provision for stop-logs. It is thus part of the structure in a weir or self-stand as in this case, through which water is drawn into a canal or pipe by extending to upstream end of a canal;

Sand trap: is an inclined trough usually made of concrete structure just downstream of an intake across which passage of any heavy particles such as sand and gravel sink/settle to the bottom and are retained in it to allow relatively silt free water to conveyance canal. Thus they act as settling basins.

Tail water depth: This is the normal depth of flow immediately downstream of the structure;

Wing walls: are also called retaining walls and are designed to protect submergence of the structure as well as the environs during flooding. They are laid on an impervious concrete floor either on one and/or both sides of the river depending on stability and nature of surrounding topography.

2 BASICES OF RIVER SIDE FREE INTAKE

2.1 BACKGROUND TO RIVER SIDE FREE INTAKE STRUCTURE

The function of any headwork structure is to divert the required amount of water at the correct head from the source into the conveyance system.

This section has accordingly deals with one of such headwork types i.e. River Side Free Intake headwork structure for direct river off take which is basically different from off takes using a weir. Such structure is thus another type of headwork structure and is normally a backward extension of Main Canal in to the river direction to be diverted usually at 45^0 to 60^0 to flow direction. Free intakes comprise, usually, an intake structure located on or near the bank of a river, which is designed and located to allow abstraction of water from the river with as little sediment as possible. Free (bank) intakes are suited to abstract only a small proportion of the river flow, and where fluctuations in water level are not too large.

Such structures are proposed when bottom levels of the Main Canal and river are comparable. Thus, there is no need for barrier construction across the river but may require only temporary ponding system. Such headwork system is cost effective but need careful design so as to harvest the required amount of flow without seriously affecting the surrounding environment and downstream ecosystem.

To minimize sediment ingress, a free intake should be located towards the downstream end of a river bend, on the outer bank. This is because the cross gradient of the water surface in a bend causes secondary flow currents, where riverbed sediment is transported from the outer to the inner bend of the river.

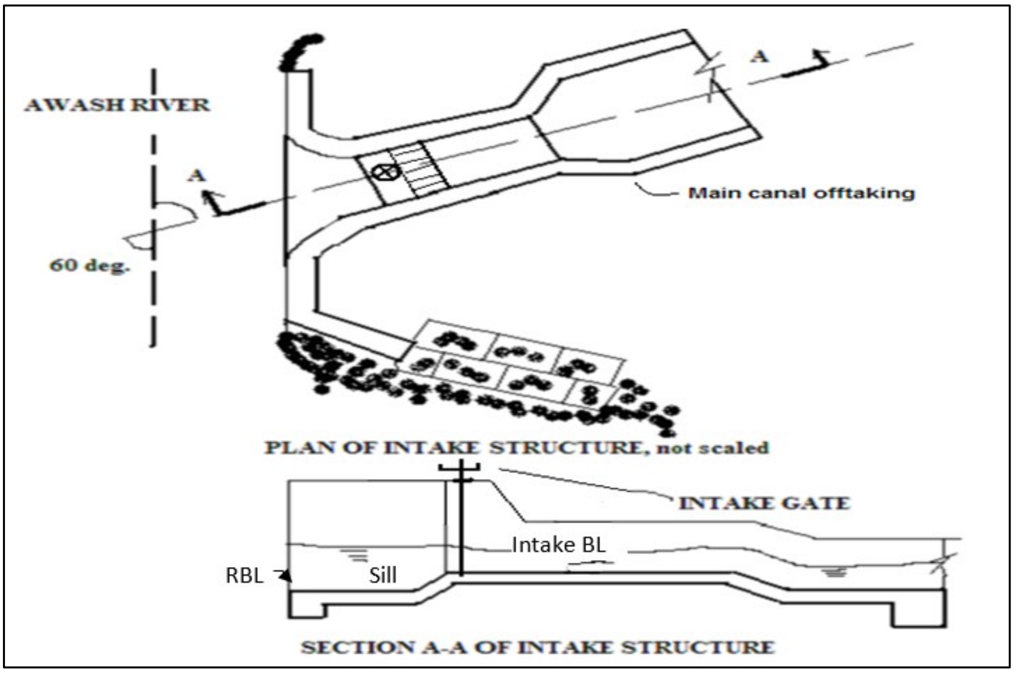


Figure 2-1: Typical intake structure (as adopted from Tibila LSIP, Ethiopia)

In rivers with a stable base flow and a high water level throughout the year in relation to the bed level of the intake canal, we can resort to run-off-river water supply system. In such headwork system introduction of a simple off-take structure is sufficient to control the water diversion to the required conveyance system. Of-course in case of alluvial channels, strengthening bed of the river with bed bars or so are required.

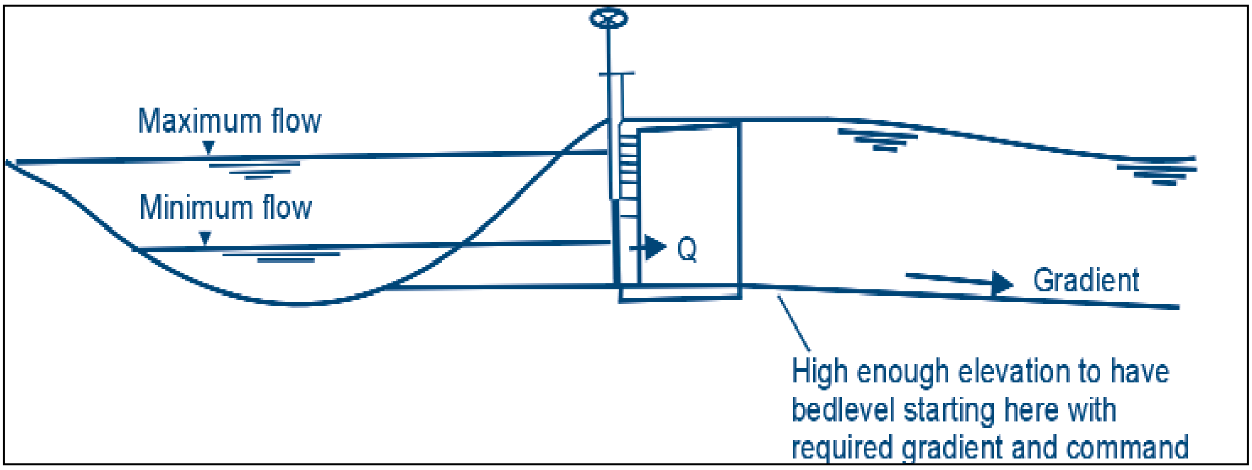


Figure 2-2: Typical cross section through river side free intake (FAO, 2002)

Table 2-1: Comparison of diversion weir and free river side intake

Parameter	Diversion Weir	Free River Side Intake
River Bed Level/RBL	Designed when RBL < CBL at its head reach	Designed when RBL ≥ CBL at its head reach
Head required to be raised	Must be raised & a minimum of 1m is required based on demand condition	Existing head is enough unless it is dammed type
Base flow requirement	It is a must unless it is spate scheme	It is a must unless it is spate scheme
Level of command area	Must be lower than RBL	Must be lower than RBL
Diversion structure	Required	Not required, unless base flow is small except bed bar
Retaining wall	Must be provided since we modify the reach	Required only on intake side unless it is unstable bank
Back water effect	Significant thus require additional protection structure	Not required unless it is of dammed type
River bed geology	Critically required, as it needs to bear weight of the structure safely	Required only from bed stabilization point of view
Investment Cost	Relatively expensive	Cheap

Figure 2-3: Intake headwork arrangement for spate irrigation, ANRS, Ethiopia, 2017

2.2 TYPES OF INTAKE STRUCTURES

Types of intake structures are chiefly distinguished by the method used to divert water from the river. According to GTZ Publication, 1989, there are three types of gated intakes which are used for diverting minimum flow of a river: namely, Lateral Intake, Bottom (Tyrolean) Intake and Overhead Intake.

2.2.1 Lateral intake

Lateral intake can be dammed or undammed. Dammed lateral intake is similar to diversion weir (as shown in figure 2-6) except that it is of shorter height and single wall on intake side. Thus dammed lateral intake is selected when a small heading up of flow is required. Inflow into such intake structure is arranged laterally and is directly dependent upon the water level in the river.

According to the minimum regime of the river, the inflow is thus limited in quantity. Another limiting factor is that, in the canal line, river bottom is normally situated at a lower level than the inlet bottom on the bank, with the result that in the inlet area, the excess head is smaller than the actual water depth of the river. The limit up to which such intake structures are suited is formed by an amount of water to be diverted of 1 to 2 m^3/s.

On the other hand, undammed type is selected when off-take to canal is possible without any heading up of river water i.e. flow depth in the river by itself is high enough to withdraw water to the canal. In most cases lateral intake without damming is suitable for the withdrawal of small amounts of water.

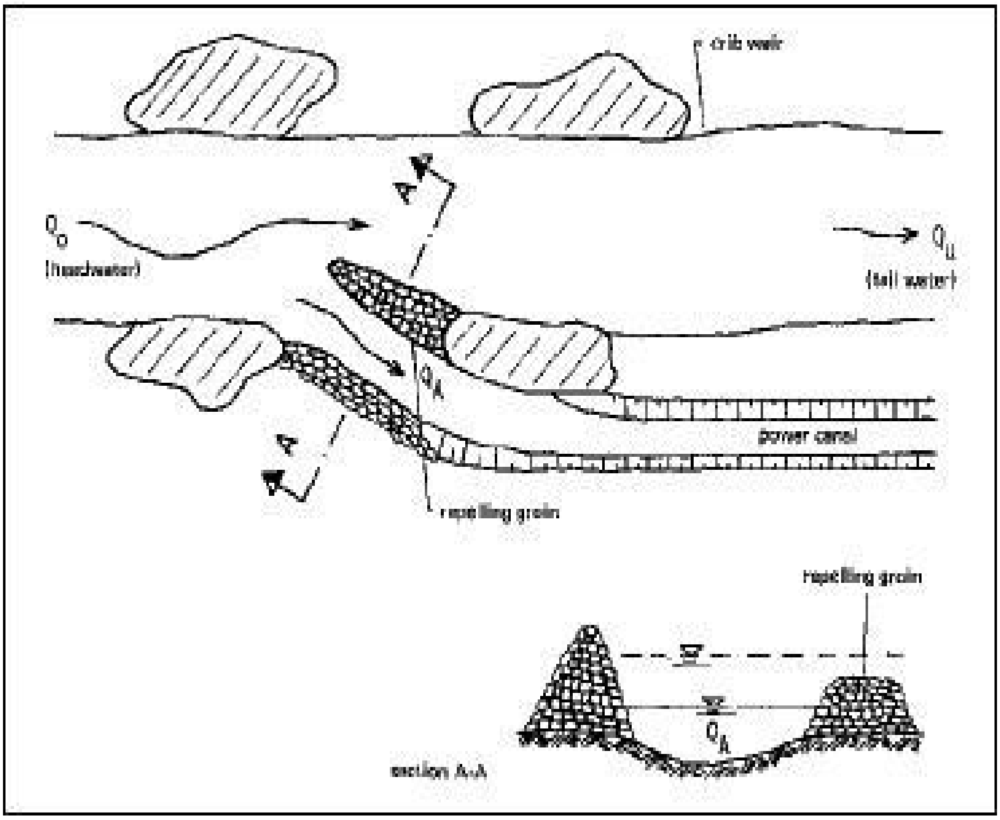
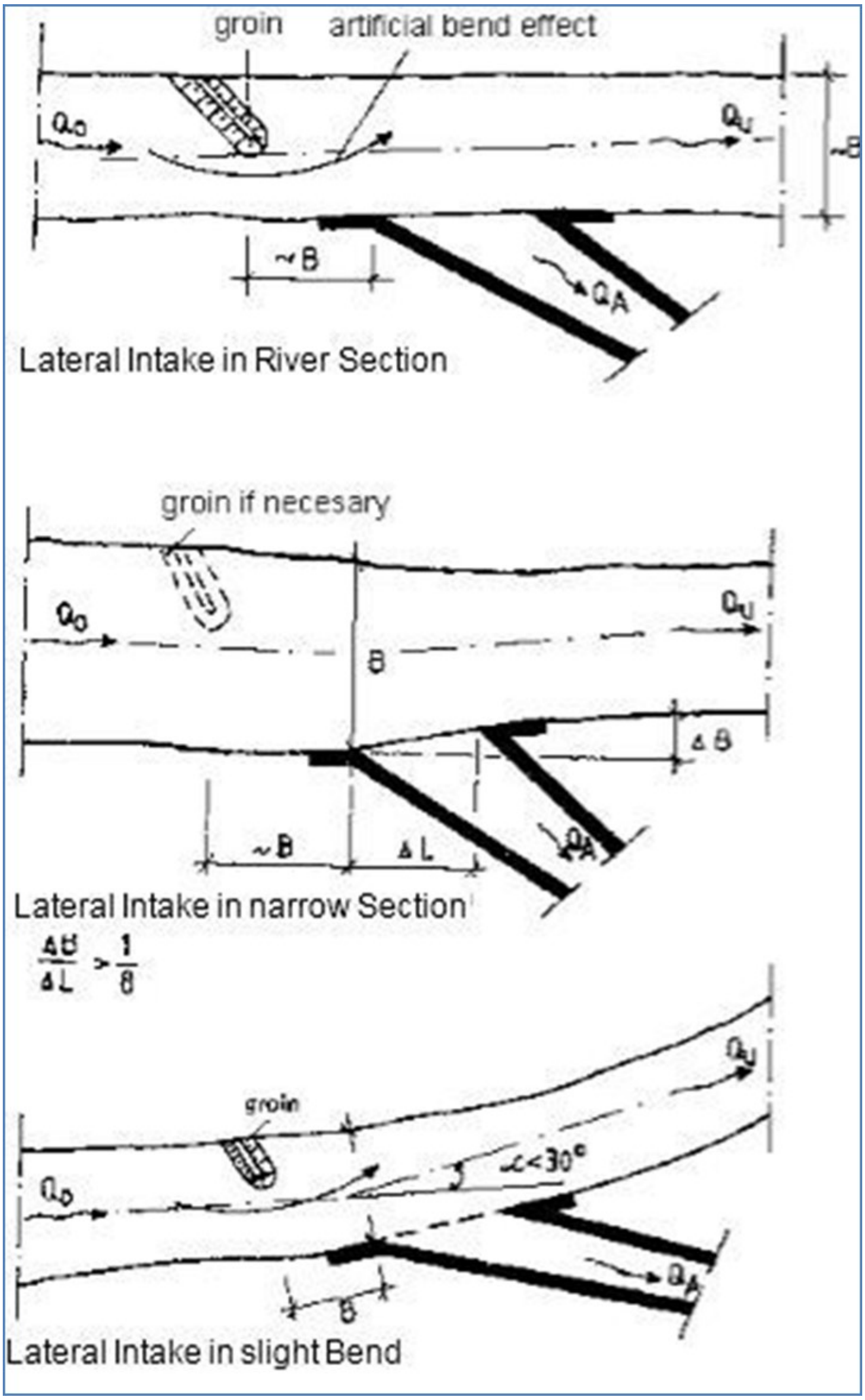


Figure 2-4: Simple intake structure without damming but with repelling groin



Source: GTZ Publication, 1989

Figure 2-5: Lateral Intake without damming and repelling of bed load from intake

Un-dammed Lateral Intake: In most cases, such lateral intake without damming is suitable only for the diversion of small amounts of water, up to 2 m^3/s. Inflow into intake structure arranged laterally is directly dependent upon water level in the river. According to minimum regime of the river, inflow is thus limited in quantity. Another limiting factor is that in the channel line, river bottom is normally situated at a lower level than the bottom of inlet on the bank, with the result that in the inlet area, the excess head is smaller than the actual water depth of the river; Thus, this type of intake without damming is suitable only in a few cases.

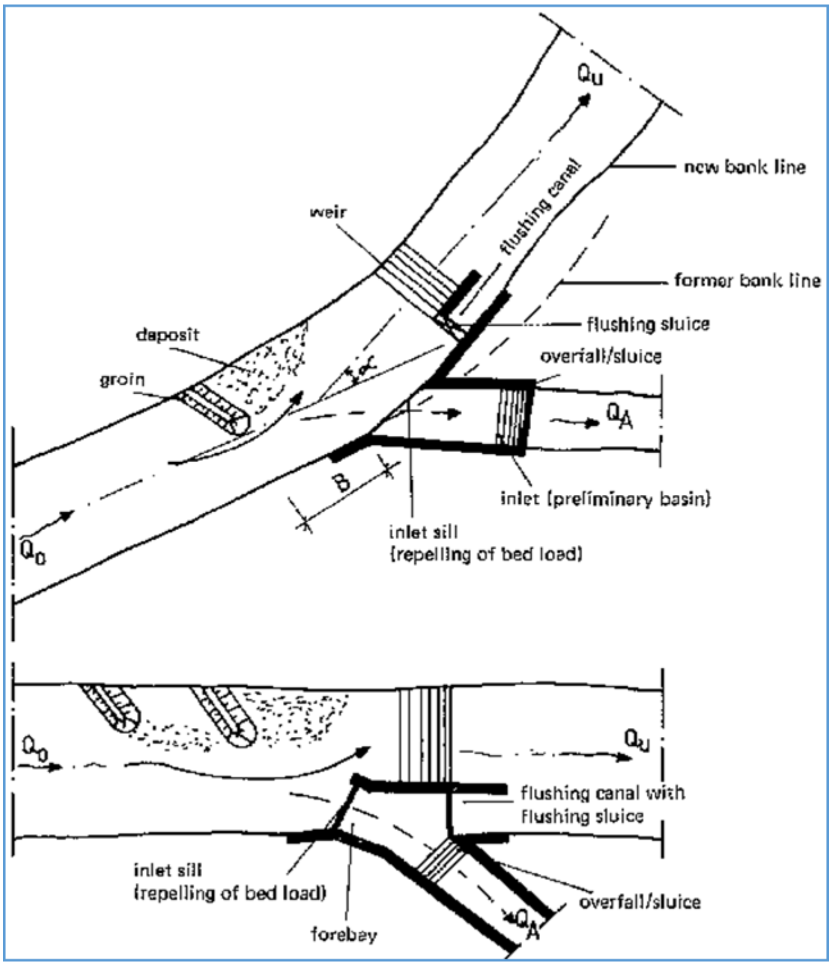


Figure 2-6: Lateral intake with damming and repelling of bed load from intake

2.2.2 Bottom intake (Tyrolean intake)

In this case, water to be diverted is taken through a canal built in to the river bottom and covered with a screen. The bars of the screen are laid in the direction of the flow so that coarse bed load is kept out of the collection canal and transported further downstream. Breast wall is also provided to limit flows in channels to the required amount.

Particles which are smaller than the inside width between the screen bars are introduced into the collection canal together with the water and these must later on be separated from the water by suitable flushing devices. The bottom intake can be constructed at the same level as the river bottom or in the form of a sill.

For the construction of such bottom intake, attention must be paid to the following points:

- Massive formation of the concrete body as it is subject to strong abrasion forces,
- Recommended angle of inclination b of the screen between 5° and 35°;
- Stable formation of the screen bars;
- Sufficient freeboard between water surface in the collection canal and upper edge of the screen (at least 0.25 t = maximum water depth in the collection canal);
- Sufficient slope in the collection canal to evacuate the solid matter which has entered through the screen, pre-sorting of this matter by the inside width between the screen bars.
- In planning dimensions of a Tyrolean intake it must be borne in mind that the whole inflow is taken from the river until the capacity limit of the screen is reached. If this

maximum possible draw-off amount is greater than the lowest discharge, the tail water is drained. If the inflow exceeds the screen's capacity limit (e.g. during flood events), the amounts which are not diverted flows through the screen into the tail water. This is why the maximum amount of water to be evacuated for our consumption can be more safely limited with a bottom intake than with a lateral intake with fixed weirs.

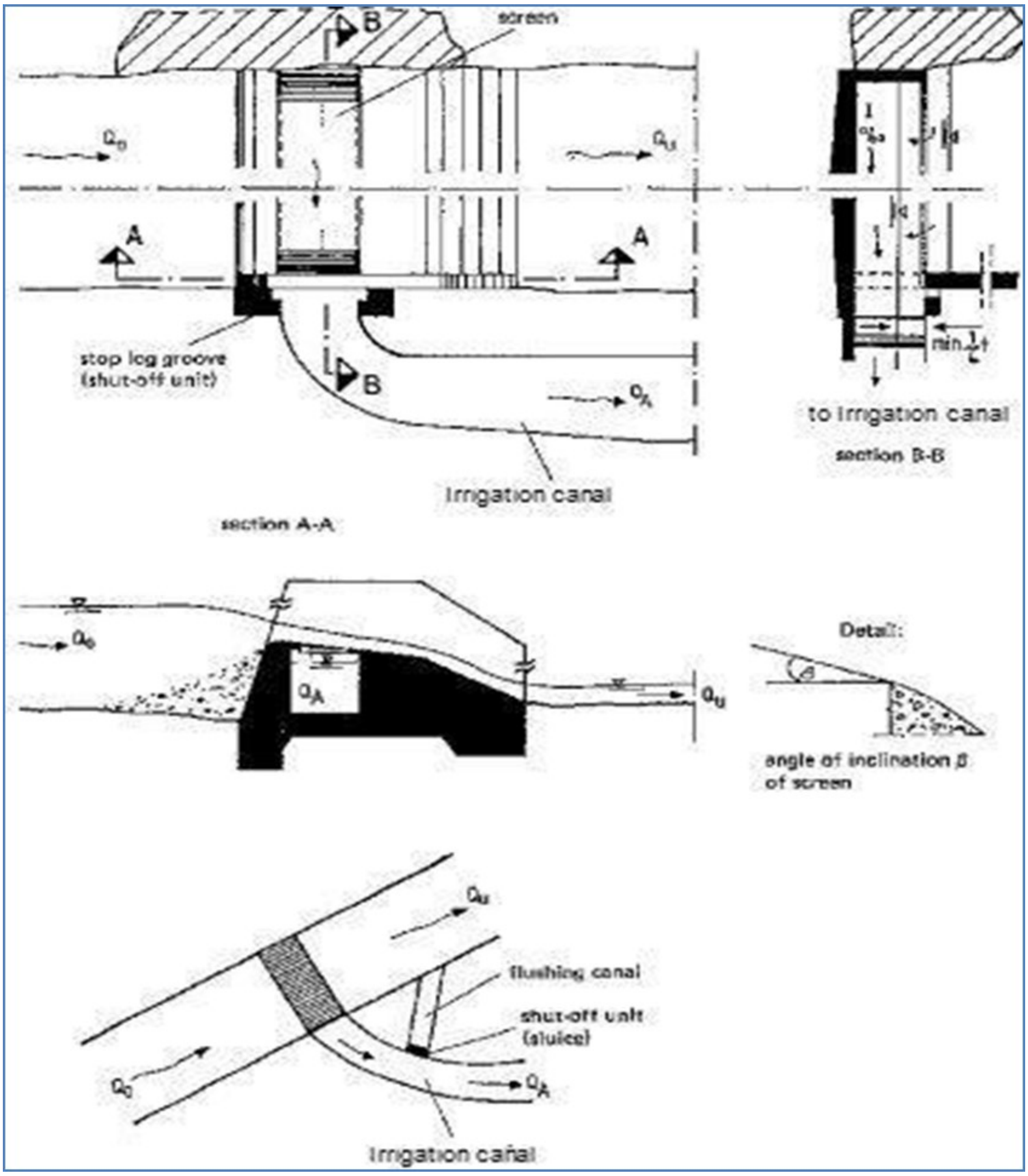


Figure 2-7: Elements of bottom intake structure with a tyrolean weir

2.2.3 Overhead Intake

This type of intake structure is an intake of water via inlets arranged in piers, as well as encroachments on the river itself, i.e. intake with & without damming up of a river. It is usually suitable for low-head power plants for energy production on large rivers, thus will not be described here in detail.

Note: For the case of dam, there is also an outlet structure known as intake tower. This is different from river side free intake, thus requires separate design considerations.

2.3 SELECTION CRITERIA FOR LATERAL AND BOTTOM INTAKE

The following table depicts criteria for selection of lateral and bottom intakes.

Table 2-2: Criteria for selection of lateral and bottom intakes

Selection criteria	Lateral intake	Bottom intake (Tyrolean weir)
Intake for water power utilization	Quite possible in connection with a sand trap	Quite possible in connection with a sand trap
Amount of water to be taken in	A favorable selection of the intake place will be a necessary prerequisite (outside bend, forcing of an artificial bend by groins) if the amount of diverted water is greater than 50% of the amount of water supplied.	Bottom screen draws off the river water up to the capacity limit of the screen.
Gradient of river:		
- Very large (I > 10%) to large (10% > I > 1%) gradient	Favorable; as maintenance-free operation of the intake structure as possible should be ensured.	Very favorable; if the intake structure is well designed, the Tyrolean Weir can prove its worth owing to maintenance-free operation.
- Mean gradient (1% > I > 0.01%)	Favorable in connection with a hydraulically very efficient sand trap.	Unfavorable; fine bed load falls into the collection canal and can result in strong alluvial deposits; difficult arrangement of the flushing installation.
- Low gradient (0.01% > I > 0.001%)	Favorable in connection with a hydraulically very efficient sand trap.	Unfavorable
Nature of river reach:		
- straight	Possible in connection with additional structures (groins for forcing a bent flow).	Very favorable, as bottom screen can be uniformly loaded.
- winding/meandering	Very favorable when arranged on the outside bend.	Unfavorable, as bottom screen cannot be uniformly loaded.
- branched	Unfavorable; damming of the river recommended.	Unfavorable
Solid matter transport of the river:		
- Suspended matter concentration:		
high	Suitable in connection with a hydraulically very efficient sand trap.	Less suitable
low	Well suited	Well suited
- Bed load transport:		
strong	Suitable as long as a sufficient amount of water remains in the river for flushing and transport purposes,	Well suited in the case of coarse bed load; expensive removal in the case of fine bed load with flushing devices.
weak	Well suited	Well suited

Source: GTZ Publication, 1989

2.4 POSSIBLE OFF-TAKING LOCATIONS

Appropriate off-taking locations depend on nature of reach of that river and its sediment carrying capacity. When the water is free from silt, the center line of the off take canal could be at an angle to the center line of the parent canal. When there is a lot of silt in the system, the off take should have a scour sluice to discharge sediments or should be put at a 90° angle from the parent canal.

If it is not possible to build the off take in a straight reach of the river, one should select a place on the outside of a bend, as silt tends to settle on the inside of bends, suspended load however, must be removed by means of a sand trap. On the other hand, erosion usually takes place on the outside of the bend and therefore protection of the bank with, for example, concrete or gabions might be needed. The off take can be perpendicular, at an angle or parallel to the riverbank, depending on site conditions.

If intake structures are arranged on bends, the intake must always be situated on the outside bend, as the bed load is transported to the inside and the arrangement of the intake structure outside allows the bed load to be largely diverted from the intake.

The most favorable site for the intake structure is somewhat downstream of the apex of the bend. The spiral flow is strongest here, causing most of the bed load to be transported towards the inner bank. If the bend in the river section is only slight, the bending effect can be increased by a groin as described above. A bend is said slight when the angle of the bend $\alpha<30°$.

Note: Free intakes may not be suitable for sediment charged rivers where high proportions of the (normal) river flows are to be abstracted, or else sediment management structures need to be installed like sediment basin/trap structures.

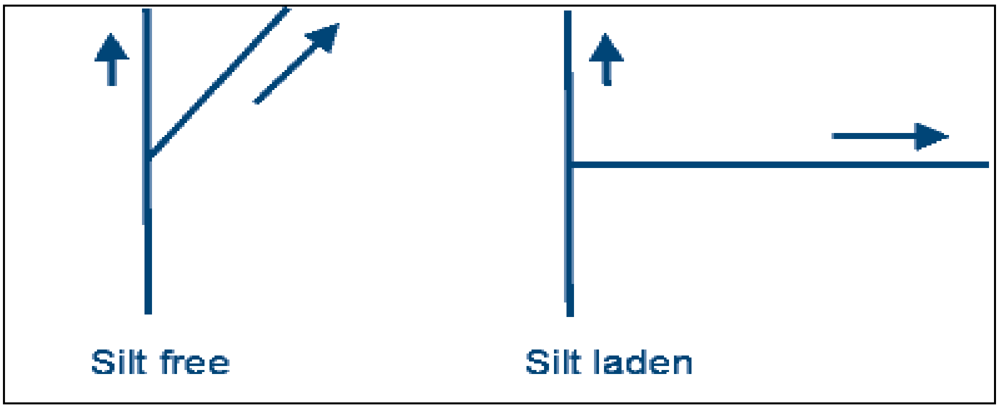


Figure 2-8: Possible off-taking locations in a river with straight reach

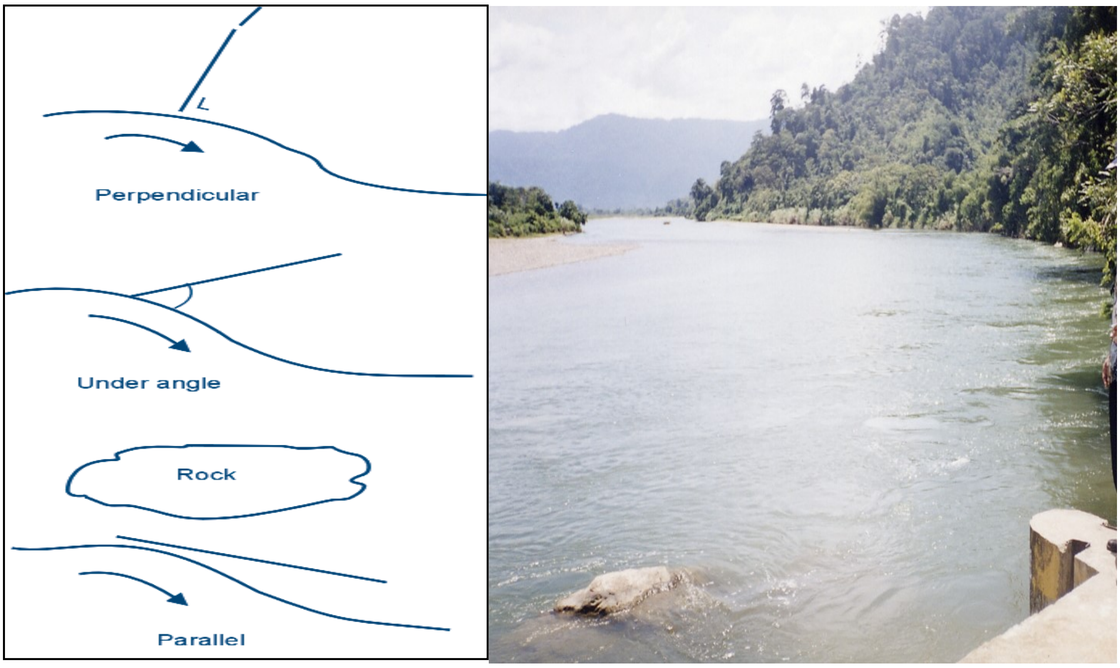


Figure 2-9: Possible off-taking locations in a river with curved reach

Intake structures should always be arranged on the river so that the following basic requirements/rules are met:

- Arrangement or construction of an intake structure must be chosen or carried out in such a way that evacuation of the necessary amount of diverted water is ensured at any regime of the channel (Regime channel is a term originating in design of stable irrigation canals. A stream channel is said to be in regime if it is transporting water and sediment in equilibrium such that there is neither scour of the channel bed and banks nor sediment deposition in the channel.);
- Peak discharges must be safely evacuated from intake structure without damage being caused. To achieve this, hydrological data must be collected & evaluated in sufficient quantity in order to enable the dimensions to be planned in accordance with safety aspects;
- A simple and moderately priced construction should be aimed, which allows maintenance-free operation & simple repairs to be carried out;
- If possible, diverted water should be free from solid matter in order to prevent diversion canal from being loaded with large amounts of bed load and/or suspended matter. To achieve this, the site of intake structures should be selected in accordance with the river training rules.

Note: If located on the downstream outer bank of a river, the intake should be aligned to the main flow so that the flow direction is changed as little as possible. Diversion angles of between 10^0 and 45^0 are recommended depending on river geometry, proportion of river flow being abstracted, etc.

2.5 FACTORS TO BE CONSIDERED WHEN SELECTING INTAKE LOCATION

Major factors which need to be considered while selecting intake locations are:

- Bed levels of conveyance canal in relation to the supply river
- River bank stability and rocky outcrops in the supply river
- River water levels and water level required to command the irrigation system
- Proportion of (normal) river flows being abstracted
- Sediment load.

It is to be noted that free intakes may not be suitable for sediment charged rivers where high proportions of the normal river flows are to be abstracted unless sufficient sediment protection mechanisms are provided.

In general, the location of an intake structure must be so chosen that the largest possible portion of the bed load remains in the river and is not taken in in the diversion canal with the diverted water. A satisfactory arrangement of the intake structure does not remove the suspended matter; this is the task of a sand trap arranged downstream.

To hold off the bed load, the natural hydraulic behavior of the river can be profited from or technical measures taken as mentioned here under.

2.5.1 Use of physical laws

In straight sections of river or stream, the water flows approximately in the cross-section of the channel, parallel to the banks. When the bed load transport begins, the bed load is transported accordingly on the bottom of the river.

In bends the direction of the bottom flow changes compared with the surface flow. A spiral flow forms which transports the bed load to the inner side of the river. On all streams and rivers it can be observed that gravel and sand banks form at the inside bend, i.e. the bed load is diverted from the deflecting bank. It could be concluded from this that the most favorable site for an intake structure is the deflecting bank.

2.5.2 Technical measures

As technical measures, bed load-deflecting structures in the form of ground sills, flushing canals, etc., in the flow area of the intake are a possibility. The following principles can be derived from the physical relationships:

- If at all possible, intake structures should be arranged on the outside bend;
- If it is necessary to construct the intake structure on a straight river section, a bent flow can be forced in order to be able to profit from natural physical laws;
- According to the rules of river training, special measures for keeping off the bed load are always necessary whenever more than 50% of the water is diverted from the river;
- In addition to the use of natural physical laws, technical measures are always necessary for intake structures where the water is not dammed up and for intake structures where the water is dammed up, as the capacity of the silting space in front of the fixed weir is limited and the entrance of bed load into the intake structure cannot be prevented in the long term.

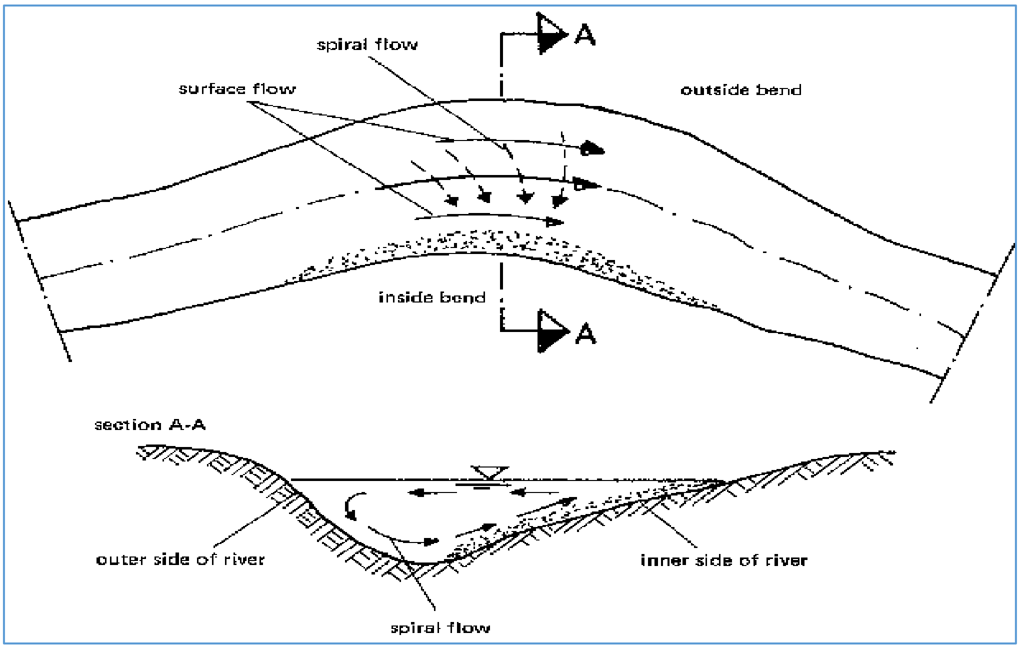


Figure 2-10: Theoretical silt depositions at a river bend

Figure 2-11: Free river side intake structure as seen on river bank (Indonesia)

2.6 COMPONENTS OF A TYPICAL FREE INTAKE

A typical free intake comprises all or part of the following components:

- Bed bar or cut off
- Screened Entry Sill or Entry Weir
- Fore bay linking the Entry Sill to the gated Main Intake
- Gated Main Intake
- Transition from Main Intake to the irrigation canal
- Silt excluder/De-silting basin/Settling Basin
- Silt Ejector channel
- Protection works of bank / wing wall.

Details of each of these components are dealt one by one in succeeding sections.

3 DESIGN OF INTAKE STRUCTURES

3.1 GETTING HYDROLOGY DATA

3.1.1 Design discharge of a river

A Design Discharge of a River at the intake site for the selected return period is paramount important fir fixing size of the structure at the top. Thus it need to be collected from the hydrology report or determined based on available flow or design rainfall data.

3.1.2 Minimum discharge of a river

Minimum discharge of a river is the lowest dependable flow below which we cannot abstract the required amount of water. If we do not intend for supplementary irrigation it will limit our design discharge of the main canal. Consequently, it has to be gathered from the hydrology report or determined based on available lean flow of the source of supply.

3.1.3 Establishing stage-discharge curve

At the outset, Stage-Discharge curve need to be established at the proposed intake point of the river to determine level corresponding to the selected return period flood (which is usually 50 years) and hence top level of retaining wall, which is usually built either on intake side alone or on both left and right banks as found necessary for the purpose of stabilizing banks of the river around the intake structure.

3.2 DESIGN CONSIDERATION OF BED BAR

Bed bar is a bed stabilizer structure across river axis. The level from Stage-Discharge curve is to be used to fix or determine hydraulic mean depth that is required in fixing bottom level of bed bar or cut off (usually of concrete) for the intake structure. This bed bar should be in monolithic with the side retaining structure for the purpose of stabilization.

3.3 DESIGN CONSIDERATION OF ELEMENTS OF LATERAL INTAKE

Elements of a typical dammed lateral intake has been shown in figure 3-1 below. Design considerations of these elements are presented in successive sub sections.

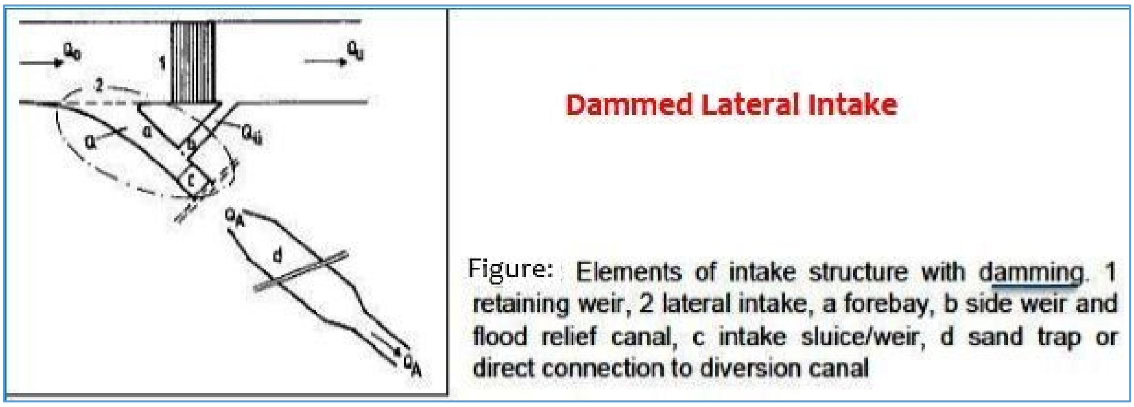


Figure 3-1: Arrangement of elements of intake structure

Note: In addition to the mentioned elements, Entry sill with screen is part of the intake structure just at the most upstream of it.

3.4 SCREENED ENTRY SILL

The Entry Sill is provided upstream of the intake structure in order to minimize the amount of sediment being transported in the river from reaching the main intake. The level of the Entry Sill is critical. It should be set at such a height above the bed of the river that the bed load and the higher concentration of the suspended sediment are excluded at high river flows, but at the same time the crest of the sill must be low enough to enable the required flow to be diverted during low river flows.

If these requirements conflict then it may be necessary to either accept increased sediment intake or reduced diverted flows, or to provide a weir or withdraw silt by sediment exclusion arrangements like rejection spillway, sand trap with canal escape or flushing channel.

The Entry Sill should be orientated parallel to the flow of the river to discourage deposition of bed load against the face of the sill.

Although the Entry Sill is set parallel to the direction of flow of the river, the axis of the Fore bay and Main Intake structure should be set at a smaller angle to the river, as described in above. The Entry Sill should be sufficiently wide to allow diversion of the required flow for the minimum 1 in 5 year low river flow.

To prevent debris, either rocks or floating wood, from entering the irrigation canal, it is common to provide trash screens, usually 50 to 150mm bar spacing, to the Entry Sill. The parallel orientation of the Entry Sill to the river flow will help prevent floating debris becoming trapped against the screens. Attention must be given to the disposal or dispersion of trapped debris.

The permissible velocity of water entering the trash rack is usually 0.75m/s. Higher velocities of up to 1.5m/s are allowed if mechanical arrangements are made to clear the trash rack(s) of debris.

It may be possible to deflect the debris at the Entry Sill to the intake. For example, where there is sufficient depth of water a deep skimmer wall extending to well below normal river flow level provides a submerged orifice, allowing entry of water while preventing the intake of floating debris.

3.5 FOREBAY

Forbay is a structure which links the Entry Sill to the Main Intake structure. To reduce turbulence, curved walls and noses to piers are recommended. A rule of thumb to prevent separation of streamlines from boundaries, as used for canals, is that the radius of the axis of flow should be at least 2.5times the width of the water surface of the canal. In practice such a large radius can seldom be provided in the Forebay, and the wall of the inner bend will be curved to suit the space available. A nosing of radius 0.2times channel width will avoid the worse effects of flow separation.

To ensure even distribution of water across the Forebay, floor baffles or vertical walls are necessary.

Where appreciable quantities of sediment are drawn over the Entry Sill, but retained by a downstream sill, provision may be made for installation of scour sluices and a sluiceway to remove sediment from the Forebay. Otherwise, as a minimum, access arrangements to facilitate manual removal of sediment from the Forebay are required.

3.6 GATED MAIN INTAKE

The Main Intake is commonly set in, or close to, the riverbank, with bank protection as required. The top of the structure is set at, or higher than, the maximum (or design) river flood level. The Intake Sill may be set lower than that of the Entry Sill, in which case consideration should be given to lowering the bed of the Forebay so that heavier particles carried over the Entry Sill are deposited in the Forebay.

In general the sill levels will define the level of the floor of the intake structure except where pumps are to be installed, in which case the floor must be lowered sufficiently for the pumps to be submerged under all operating conditions.

The Main Intake is gated so that flow diversions may be regulated, and shut off if necessary during floods to prevent ingress of sediment.

The area of the entrance to the gated Main Intake through which supply is passed is sized to give an acceptable maximum velocity, say 1 to 2m/s for open channel flow.

3.7 TRANSITION

Transition is part of the intake headwork structure which is provided to link the Gated Main Intake to the irrigation/approach channel. Its shape is usually designed either converging or diverging based on size of approach channel though it is normally converging type for improving intake efficiency and economize the cross section. It should be symmetrical about the centerline of the upstream Main Intake and the receiving canal. It is designed so as to prevent formation of waves which can be troublesome as they travel through the head reach of canal section (For its design, refer equation 4-2).

3.8 BED BAR

Bed bar is a buried wall laid across a river or at a 90 to 120 degree from the flow direction upwards with its top at, or slightly above, river bed level and is intended to prevent the lowering i.e. for stabilizing of the channel adjacent to the canal intake effectively.

The likely mechanisms of failure of such structures would include abrasion, impact and the development of a scour hole on the downstream side, resulting in its overturning. Retrogression of the downstream bed would turn the bed bar into a drop structure which would eventually cause failure. However, this is unlikely to occur unless there is substantial material extraction downstream of the structure. The high sediment loads during floods are more likely to cause bed aggradations.

The design of bed bars is usually from reinforced concrete, masonry or gabion. Studies of such works indicate that gabion works inside the main river/channel are vulnerable to severe damage during large floods. Therefore the preferred material for bed bars is mostly mass concrete, which can be cast into excavated trenches.

Usually 0.3m to 0.6m thick bed bar inclined at 90 to 120 degree from the flow direction upwards is provided to stabilize the channel flow. The depth of bed bar is fixed by cut off principle, from Lacey's formula i.e. normal scour depth, R is given by:

$R=1.35*(q^2//f)^{1/3}$ ……………………………………………………………………………… (3-1)

Where, q is a unit discharge or discharge intensity and is given by $q= Q_{50}/L$,

Q_{50} is peak flood corresponding to 50 years return period

L is river width or length

f is Lacey's silt Factor & given by $f=1.76*\sqrt{d_{50}}$, and

d_{50} is particle diameter corresponding to its 50% distribution

3.9 DESIGN OF INTAKE STRUCTURE

3.9.1 Data requirements

Date requirements include:

- Topographical data of the river channel both upstream and downstream of the proposed intake/weir site, including river cross-sections.
- Hydrological data including river flood and low flows and associated river levels.
- Geotechnical data including riverbed material, and features such as rock outcrops, etc.
- Sediment load data.

3.9.2 Design considerations and computations of intake structure

Whether an intake is chosen with or without a river dam depends not only upon the cost of the weir. The following aspects should also be taken into consideration:

- The topographical conditions upstream of the structure. Damming up results in a backflow in the channel leading to a rise in the water level, which in turn may lead to flooding of the bank areas far upstream of the structure;
- The geotechnical conditions of the bank zones (talus material or rock);
- Height of the bank above the river bottom;
- The ratio of the quantity of diverted water to the residual quantity of water in the river at low discharge, with regard to existing rights of use of the downstream users;
- The channel width in the tapping point (dependence of the water level at times of low discharge in the river; meandering at low discharge in wide rivers, etc.; cost of damming structure, etc.);
- The routing of the diversion canal;
- The intake structure must not narrow the cross-section of flow of the channel; otherwise, at peak discharges, the bottom erosion in the area of the intake structure in the river bed would be increased, which in turn results in a change of the water level. A safe diversion of water at low discharges is therefore no longer ensured.

Such structures should be so designed that:

- At times of the lowest discharge, the required amount of water QA can always be diverted,
- All floods, including the design flood, can be evacuated without damage being caused to structures or objects, or danger to life and limb,
- The amount of water flowing into the canal is limited to the amount of water to be diverted Q_A. This can be achieved by installing suitable structures in the inlet or by spillways.

Design computations of intake in general are similar to that covered in weir design and include determination of:

- Flow depths in river for various discharges;
- Flows and head losses over sills, though trash screens, through intake structure components, etc.

- Scour depth, seepage & uplift;
- Structural stability

Based on the functions of intake structures i.e. to pass required design discharge into a conveyance canal or pipeline and to prevent excessive water from entering during flood, the most important aspects of the structure is control arrangement, which can be a gate, stop logs, or other similar structures. When the gate is fully opened, the intake behaves like a submerged weir and hence its discharge is given by the equation:

$$Q = C * B * (h + h_d)^{3/2} \quad \text{(3-2)}$$

Where:
- Q = Discharge in intake (m^3/sec)
- C = Weir coefficient
- B = Width of the intake (m)
- h = Difference between river water level and canal design water level (m)
- h_d = Difference between canal design water level and sill level of the intake (m)

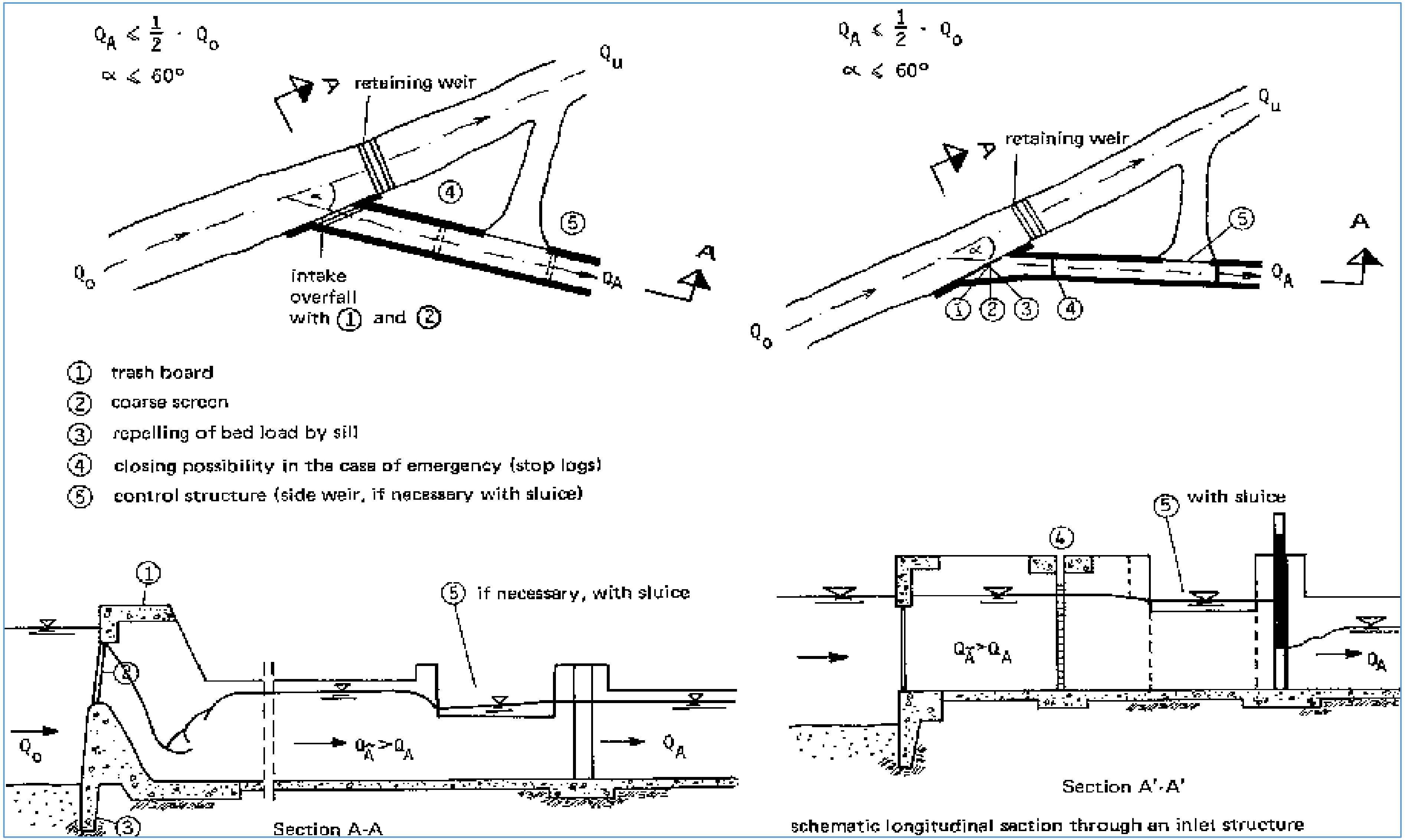


Figure 3-2: Schematic Possible Arrangement of Intake Structure Elements (Plan & Section)

3.10 STRUCTURAL DESIGN OF FREE INTAKE

3.10.1 Structural design considerations

This section provides the criteria for structural design aspects of a free intake section which involves stability and sizing of the structure following the hydraulic requirements stated in preceding sections.

All structures should be checked for the safety against stability and stress conditions. The major factors involved in the structural design aspects are construction materials, various loads to be considered and factor of safety to be adopted.
According to our current construction industry's practice, for small scale irrigation project construction, Stone masonry and reinforced concrete are the dominant structural unit used for free intake structures design. Steel Structures are also in use for gates, ladders and hand-railing purposes.

3.10.2 Loads on structures

The principal load which should be considered for structural design of free intake are self-weight, earth pressure, water pressure including uplift, imposed live load such as live load at get operation platform, earth quake load and wind load.

Operating decks for the free intake shall be designed for a uniform live load of 7.2 KN/m^2.

3.10.3 Basic engineering property of materials

Table 3-1: Unit weight of basic materials

Dead Loads	Weight (KN/m^3)
Water	9.81
Stone masonry	21
Brick masonry	21
Mass concrete	24
Reinforced concrete	25
Steel	78.5
Timber (steel)	8
Wood (teak)	6
Dry backfill	16
Saturated backfill	20
Submerged backfill	10.2
Dry, compacted backfill	18.5
Saturated compacted backfill	21.5
Submerged compacted backfill	11.7
Gabions	14

Table 3-2: Internal angle of friction (∅) of soil

Soil type	ø
Gravel	45° - 55°
Sandy - gravel	35° - 50°
Sandy - loose	28° - 34°
- dense	34° - 45°
Silt, silly sand - loose	20° - 22°
- dense	25° - 30°

Table 3-3: Allowable bearing pressure of soils

Soil Type	Allowable Bearing Pressure KN/M^2
Soft Clays And Silts	< 80
Firm Clays And Firm Sandy Clays	100
Stiff Clays And Stiff Sandy Clays	200
Very Stiff Boulder Clays	350
Loose Well Graded Sands And Gravel/Sand Mixtures	100
Compact Well Graded Sands And Gravel/Sand Mixture	200
Loose Uniform Sands	<100
Compact Uniform Sands	150

Note: That for dynamic loads, a 25% overstress may be allowed

3.10.4 Concrete grade

Concrete is graded in terms of its characteristics strength. Compressive strength of concrete is determined from tests on 150mm cubes at the age of 28 days in accordance with standard issued or approved by Ethiopian Standard. Table below gives the permissible grades of concrete for the two classes of concrete works. The number in the grade designation denotes the specified characteristics compressive strength in MPa.

Table 3-4: Permissible grade of concrete

Class	Permissible Grades of Concrete							
I	C5	C15	C20	C25	C30	C40	C50	C60
II	C5	C15	C20					
Nature	Plain		Reinforced					

3.10.5 Reinforcement steel

The characteristic tensile strength of reinforcement bar to be used shall have yield strength not less than 400MPa (fy=fck= 400MPa to be used for design in this guideline).

The mean value of Modulus of Elasticity of reinforcement bar (E_s) can be assumed as 200GPa. Minimum Reinforcement Provision is required to control the concrete crack during the immature age and the minimum reinforcement required shall be provided as per table below.

Table 3-5: Minimum re-bars required for crack control of immature concrete

Structural Element	Thickness Of Element (h)	Minimum Reinforcement (mm^2)*	
		Top Face	Bottom Face
Walls And Suspended Slabs	h Less Than 500 mm	3.25 X h/2	In Both Faces
	h Greater Than 500 mm	3.25 X 250	In Both Faces
Ground Slabs	h Less Than 300 mm	3.25 X h/2	0
	h Between 300 mm And 500 mm	3.25 X h/2	3.25 X 100
	h Greater Than 500 mm	3.25 X 250	**2.25** x 100

* MINIMUM REINFORCEMENT PER METER RUN.

3.10.6 Structural analysis

Structural Analysis is the process for the determination of the actions on the structure due to all the possible applied loads as mentioned in section 3.9.2 above, load on structures. The main actions obtained after the structural analysis are bending moment, Shear force and axial force. The analysis can be carried out manually with the help of equilibrium equations for simple determinate type structure, however for indeterminate type problem, the use of software application like SAP-2000 is preferred for accuracy and time saving purpose. Following the completion of the analysis, the design of the member size and reinforcement requirement shall be carried out based on the limit state design.

3.10.7 Limit state design

In this guideline the limit state design will be in use as this method is the acceptable current practice by our local codes and other international codes. The limit state method multiplies the working load by partial factor of safety and also divide the materials ultimate strength by further partial factor of safety.

Table 3-6: Partial safety factor applied to material (γ_m)

Limit State	Material	
	Concrete	Steel
Ultimate		
Flexure	1.5	1.15
Shear	1.25	1.15
Bond	1.4	
Serviceability	1	1

Table 3-7: Partial factor of safety for loadings

Load Combination	Ultimate				Serviceability
	Dead	Imposed	Earth & Water	Wind	All
Dead & Imposed (+ Earth & Water)	1.4 (Or 1)	1.6 (Or 0.0)	1.4	-	1.0
Dead & Wind (+ Earth & Water)	1.4 (Or 1)	-	1.4	1.4	1.0
Dead & Imposed & Wind (+ Earth & Water)	1.2	1.2	1.2	1.2	1.0

The lower values in brackets applied to dead or imposed loads at the ultimate limit state should be used when minimum loading is critical.

For small scale intake headwork structure design, the structural strength requirement check for bending moment (flexure), shear force and axial stress would be quite sufficient.

3.10.8 Flexural design of reinforced concrete member

The theory of bending for reinforced concrete assumes that the concrete will crack in the regions of tensile strains and that after cracking all the tension is carried by the reinforcement. It is also assumed that plane section of a structural member remains plane after straining, so that across the section there must be a linear distribution of strains.

Figure below shows the cross section of a member subjected to bending and the resultant strain diagram together with 3 different types of stresses distribution in the concrete.

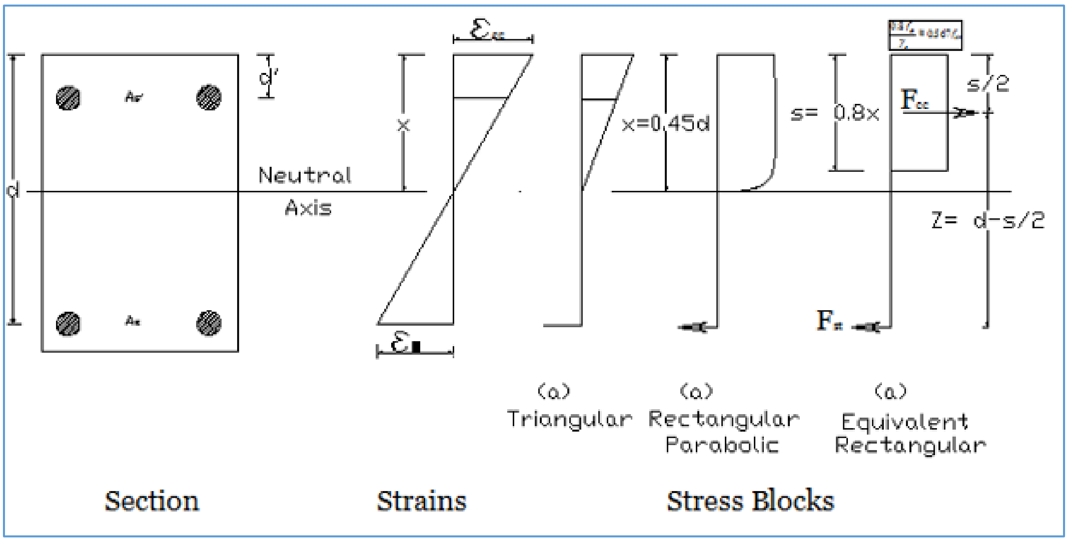


Figure 3-3: Section with stress diagram & stress block for singly reinforced section

(1) The triangular stress distribution applies when the stresses are very nearly proportional to the strains, which generally occurs at the loading levels encountered under working conditions and it is, therefore, used at serviceability limit state.

(2) The rectangular – parabolic stress block represents the distribution at failure when the compressive strains are within the plastic range and it is associated with the design for the ultimate limit state.

(3) The equivalent rectangular stress block is a simplified alternative to the rectangular – parabolic distribution.

For singly reinforced section in equilibrium, the ultimate design moment, M, must be balanced by the moment of resistance of the section so that,

$$M = F_{cc}\, x\, z = F_{st} z \qquad (3\text{-}3)$$

Where, z is the lever arm between the resultant force F_{cc} and F_{st}

$$F_{cc} = 0.567 f_{ck} bs \qquad (3\text{-}4)$$

$$M = 0.567 f_{ck} bsz \qquad (3\text{-}5)$$

$$z = d - \frac{s}{2} \qquad (3\text{-}6)$$

$$M = 1.134 f_{ck} b(d - z)z \qquad (3\text{-}7)$$

$$K = \frac{M}{bd^2 f_{ck}} \qquad (3\text{-}8)$$

Therefore,

$$z = d\left[0.5 + \sqrt{0.25 - k/1.134}\right] \qquad (3\text{-}9)$$

Hence,

$$A_s = \frac{M}{0.87 f_{yk} z} \qquad (3\text{-}10)$$

The lower limit for the lever arm can be determined from the limit depth of the neutral axis that is x=0.45d, Minimum lever arm limit is therefore:

z= d-(0.8*0.45d/2)= 0.82d ………………………………………………………… (3-11)

Hence, for balanced failure,

M_{bal} = 1.134*f_{ck}b(d-0.82d)*0.82d = 0.167f_{ck}bd^2 …………………………….. (3-12)

Therefore,

$$\frac{M_{bal}}{bd^2 f_{ck}} = K_{bal} \quad \text{……………………………………………………………………..} \quad (3\text{-}13)$$

For section to be designed as single reinforcement and failure first to happen in yielding

$K_{bal} < 0.167$ ……………………………..…………..………………………… (3-14)

3.10.9 Shear Resistance design of reinforced concrete member

It is inconvenient to use shear reinforcement in slabs because it is difficult to fix, impends placing of concrete, and is inefficient in the use of steel. The wall or base slab thickness therefore should be at least sufficient to allow the ultimate shear force to be resisted by the concrete in combination with the longitudinal reinforcement. Maximum ultimate shear carrying capacity of reinforced concrete slab is given by equation 3-15 below as per British Standard (BS 8110).

$$\upsilon_c = \left(0.79\left(\frac{f_{ck}}{25}\right)^{\frac{1}{3}}\left(\frac{100A_s}{bd}\right)^{\frac{1}{3}}\left(\frac{400}{d}\right)^{1/4}\right)/\gamma_m \quad \text{…………………………………} \quad (3\text{-}15)$$

The steel ration should not be taken as greater than 3. The value of effective depth (d) should not be taken more than 400mm and fck should not be taken as greater than 40N/mm2 and γ_m shall be taken as 1.25, where A_s is area of steel.

3.10.10 Stone masonry design

i. General

In most cases of small scale irrigation schemes intake headwork structure construction, the use of stone masonry structural as side soil retaining work is a common practice. Compared to other construction materials, masonry is relatively cheap and easy to work with. One major disadvantage of masonry work is that its capacity to withstand tension is very limited. Due to this, it will be necessary to check the magnitude of tension force at critical sections. The unit weight for Stone masonry and soil for design purpose can be taken from Table 3.1 above.

Active earth pressure shall be calculated based on Equation 3-16 below.

$$K_a = \frac{1-sin\emptyset}{1+sin\emptyset} \quad \text{……………………………..………..………………………..} \quad (3\text{-}16)$$

$$p_s = \frac{1}{2} k_a \gamma_s h^2 \quad \text{…………………..……..…………..………………………..} \quad (3\text{-}17)$$

Where, Ka is coefficient of active earth pressure, (unit less)

$\emptyset$ is angle of internal friction of the soil (^{0})

P_s is pressure exerted by backfill soil or deposited silt, if any, (KN/m)

γ_s is unit weight of soil, (KN/m^3)

h is height of soil under consideration (m)

ii. Design assumptions

The followings are some of the assumptions that need to be considered during design:

a) When a surcharge load is to be considered, the value of surcharge load should be taken according to the nature of fill and slope of surcharge.
b) For Hydraulic structures, 2/3 of the bottom soil is assumed to be saturated.
c) The triangular wedge of the retained soil is assumed to assist the stabilizing effect.
d) The passive earth pressure is assumed to be counter-blocked by an equivalent active pressure.

iii. Stability analysis

The following procedures shall be used in stability analysis of a retaining wall.

a) Consider unit length of the structure (Retaining Wall)
b) Work out the magnitude and direction of all the vertical forces acting on the structure and their algebraic sum i.e. ∑V.
c) Similarly work out all the horizontal forces and their algebraic sum i.e. ∑H.
d) Determine the lever arm of all these forces about the toe.
e) Determine the moments of all these forces about the toe and find out the algebraic sum of all those moments i.e. ∑M.
f) Find out the location of the resultant forces by determining its distance from the toe, i.e.

$$\bar{X} = \frac{\sum M}{\sum V} \quad \text{.......................................} \quad (3\text{-}18)$$

g) Find out the eccentricity e of the resultant using, i.e.

$$e = \frac{B}{2} - \bar{X} \quad \text{.......................................} \quad (3\text{-}19)$$

h) Determine the vertical stresses at the toe and heel using:

$$P_v = \frac{\sum V}{B}\left[1 \pm \frac{6e}{b}\right] \quad \text{.......................................} \quad (3\text{-}20)$$

i) Determine the factor of safety against to overturning as equal to:

$$F.O.S = \frac{\sum Stablising\ Moment(+)}{\sum Diturbing\ Moment\ (-)} \quad \text{.......................................} \quad (3\text{-}21)$$

Minimum F.O.S shall be = 2.00

j) Determine the factor of safety against sliding, using sliding factor, it must be greater than 1.

$$Sliding\ Factor = \frac{\tan\emptyset \sum V}{\sum H} \quad \text{.......................................} \quad (3\text{-}22)$$

Where, $\emptyset$ = Angle of friction of the soil

Minimum Sliding Factor shall be $= 1.5$

Box 3-1:

Worked Example-1: It is necessary to divert a discharge of 0.4 m3/sec directly from river side to be abstracted from a river into an open conveyance canal. The level of base flow in the river is 1225.35 m and the level of water designed in the canal is 1224.90 m and the required water depth in the canal is 0.60 m. If width of the intake is of 0.4m, design efficient free intake system based on the provided design data.

For Broad Crested Weir, Weir Coefficient, C = 1.7.
Head difference from River base flow to Canal Full Supply level, h = 1225.35-1224.90= 0.45m
Width of intake, B= 0.4m, Assumed Value.
From weir flow equation 2.1, the sill height, hd can be fixed as:
$0.4 = 1.7*0.7*(0.45+hd)^{3/2}$, Thus $h_d = (0.4/(1.7*0.4))^{2/3} -0.45 = 0.25$m
Therefore, Sill Level = 1224.90-0.25 = 1224.65m
Canal Bed Level = 1224.90- 0.50 = 1224.40m

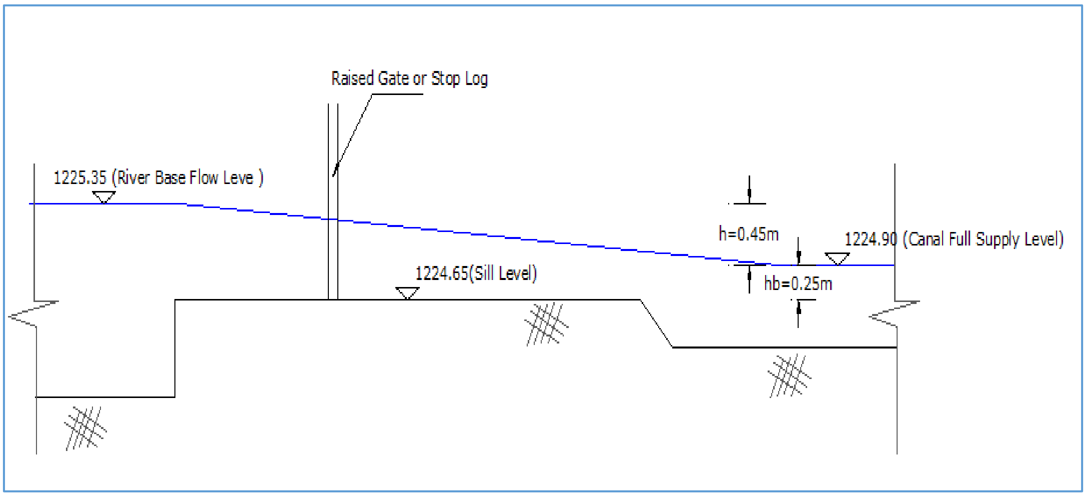


Figure 3-4: Free river side intake cross section for the worked example

Note: For Stability analysis of wing wall section and dammed section, refer GL B8: SSIP Guideline for Diversion Weir Design.

4 SAND TRAPS

4.1 GENERAL

Each river entrains solid matter in the form of suspended matter or as bed load or both. The location of an intake structure thus must be so chosen that the largest possible portion of the bed load remains in the river and is not taken in to the conveyance canal with the diverted water. A satisfactory arrangement of the intake structure however does not remove the suspended matter rather this is the task of a sand trap arranged downstream of it.

Sand Traps are provided for sediment laden water (otherwise it may not be required) just downstream of river intakes to allow it settle and then discharge it to the river latter. They should be designed to settle out sand and gravel under normal operating conditions and for this material to be scoured out under flushing conditions.

4.2 CONTROL OF SEDIMENT AT RIVER INTAKES

4.2.1 General

Extraction of water from rivers is one of the most ancient human activities in the field of hydraulic engineering. Nevertheless, the design of an intake structure in a natural river still belongs to the most delicate tasks even in our days. Problems arise mainly from the fact that in natural rivers besides the water also a considerable amount of sediment is transported. Therefore, the designers of intake structures repeatedly find themselves confronted with the problem of how to take the water out of the river while leaving the sediment behind.

Separation of water from sediment moving close to the bed is somewhat easier to handle than the exclusion of sediment in suspension. There are numerous methods and techniques which are basically based on a single principle, namely the application of a horizontal divider, separating the upper layers containing mostly pure water from the sediment-laden lower layers. A comprehensive description of a large number of methods and techniques of this kind has been given by Scheuerlein, 1984. Although the sediment control techniques considered here can be traced back to a common basic principle, they differ widely in some other respects. Three major groups can be identified:

- Sediment rejection (at entrance to the intake),
- Sediment extraction (within the settling basin) and
- Sediment ejection (from the basin).

4.2.2 Sediment rejection

The principle of sediment rejection is that, while the upper layers of the flow are allowed to enter the intake, the lower layers are kept from entering the intake and conveyed towards downstream with the remaining river flow. For this method, various kinds of submerged sills and bars are used to keep the sediment from entering the intake. In many cases also advantage is taken of the occurrence of natural secondary currents providing favorable flow patterns in the vicinity of the intake (for instance, at the outside of bends where the flow close to the bed tends to move away from the intake). When favorable natural flow patterns are lacking, very often auxiliary measures are applied as, for instance, spur dikes, floating pontoons, training walls, cantilever sills, etc. as given by Scheuerlein in the cited source.

The principle of sediment rejection can also be applied when the intake is not combined with a diversion dam. With proper design, the sediment rejection technique can allow for diversion up to 50 per cent of the total river flow without encountering bed load problems at the intake. (Visit sediment transport references for details).

4.3 COMPONENTS OF SAND TRAPS

A sand and grit trap is part of an inlet structure which comprises an inlet transition, settling basin(s), an outlet transition, control section and flushing sluiceway(s).

The sand trap inlet should be located at least $10W_s$ downstream of the intake, where W_s is the water surface width of the off-taking canal, so that turbulence induced by flow through the intake would be decayed …………………………………...………………………………... (4-1)

To prevent separation, the inlet transition walls should not diverge sharper than 1:5 and the outlet transition walls should not converge sharper than 1:3 …………………………….…... (4-2)

The settling basin(s) total area should be sufficiently large to settle out gravel and the coarser sand particles. An initial estimate for the surface area of the settling basin is given by:

Initial basin width, $W_{sb} = 5Q_d^{0.5}$ (m) ..…………………………………………….….……... (4-3)
Basin Length, $L_b = 8W_{sb}$ (m) ……………………………………...…………………… (4-4)

Where, Q_d is the design discharge for the intake i.e. the main canal (m^3/s).

The control section at the downstream end of the trap is gated and allows flow to either return to the river via the flushing sluiceway to scour sediment deposited in the settling basins, or to flow into the conveyance canal(s).

4.4 DESIGN OF SAND TRAP

4.4.1 *Introduction*

A sand trap settling basin's size is determined for the design intake flow. The settling basin(s) accommodate sediment settled out during normal operation. When the accumulated sediment is to be flushed from the settling basin(s) back to the river, the flushing sluiceway gate(s) are opened. The slope of the bottom of the settling basin(s) and of the flushing sluiceway must been sufficiently steep to flush out accumulated sediment.

The flushing sluiceway returns flow to the river, where the sluiceway bed level must be above riverbed level. If excess head remains then a glacis drop may be provided. If this is not the case, either the bed-bar crest has to be raised to increase available head, or the length and capacity of the sand trap have to be reduced.

In general, a sand trap should have sufficient capacity so that flushing is required weekly, bi-weekly or monthly.

The tail of the sluiceway at the river may also have to be gated or provided with stop logs, and is generally provided with RCC breast walls to prevent river flow backing up towards the sand trap during floods. The following two sections give steps in the design of a sand trap.

4.4.2 Design of sand trap under normal operating conditions

Step 1: Adopt a maximum sediment size (D_{max}) that is to be settled out in the settling basin under normal operating conditions. Typically, for designing sand traps this value ranges between 0.6mm and 0.2 mm (average value being 0.3mm). This will result in only (fine) sand and silt entering the irrigation canal system, which will probably mostly be transported to farmers' fields (Refer Figure 4.2). Then determine the fall velocity of the D_{max} sediment from Figure 4-3. For 0.3mm particles the fall velocity (W) is commonly about 0.04m/s.

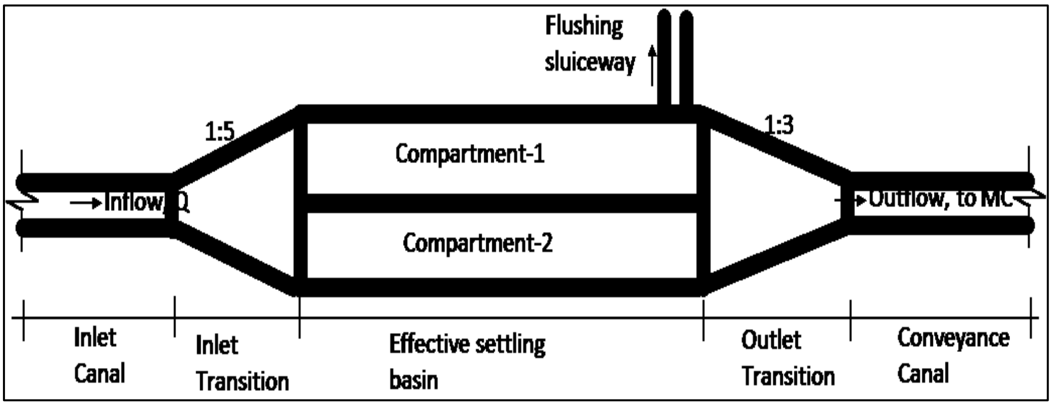


Figure 4-1: Typical double-basin sand-trap plan

For soil triangle of basic soil textural classes refer appendix

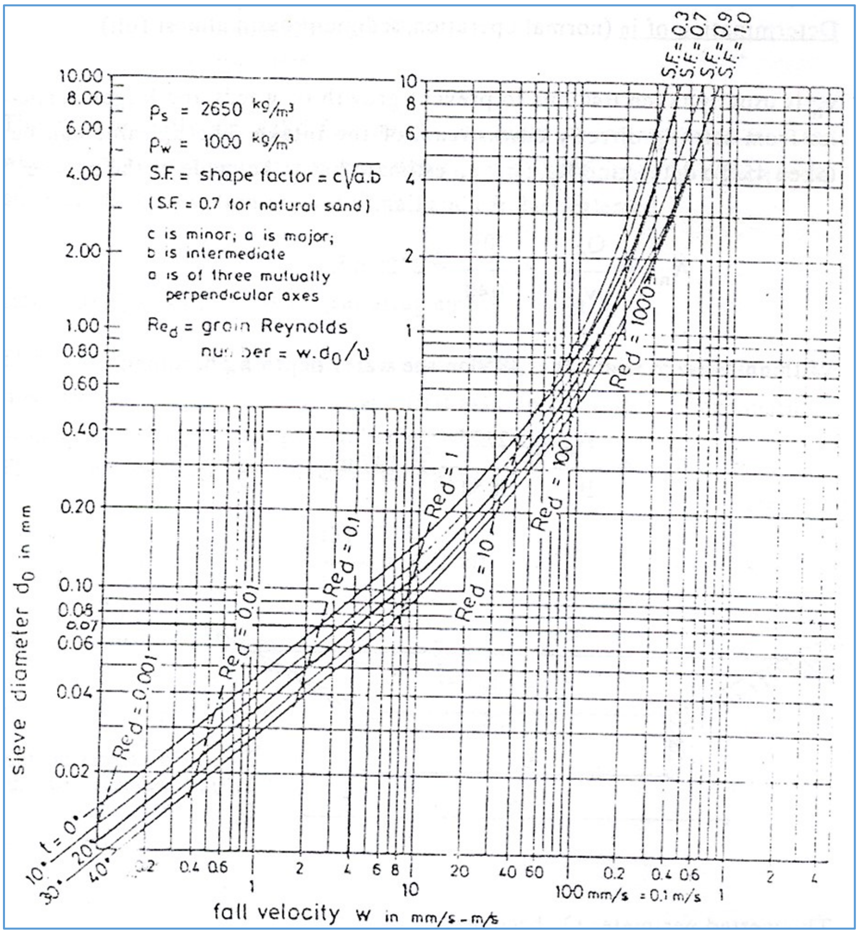


Figure 4-2: Relationship between sieve diameter & fall velocity for still water

Step 2: Use Vetter's settling basin design equation to determine the required surface area for the settling basin:

$X_{out}/X_{in} = 1 – e^{(-w\ A/Q_d)}$ …………………………………………...………………..…… (4-5)

Where:

X_{out}/X_{in} = Trap efficiency, usually an efficiency of 99% is adopted.
W = fall velocity for D_{max} particle (m/s)
Q_d = Design discharge for the irrigation canal (m^3/s).
A = Surface area of settling basin (m^2).

Rearranging Vetter's equation gives:

A = 4.605 Q_d / W (m^2) ……………………..……………………...…………………… (4-6)

Step 3: Use additional Safety Factor for designing sand traps, i.e. if the Initial Surface Area to be estimated is greater than 1.25 times the Vetter's Area, then an area of 1.25*Vetter's Area is to be adopted. If the Initial Surface Area to be estimated is less than the 1.25 times the Vetter's Area, then the Vetter's Area is to be adopted.

Step 4: Adopt dimensions for the settling basin so that the length (L_b) = 8 to 10 times its width (W_{sb}) ……………………..……………………...………………………………………………... (4-7)

Note: A shorter wider basin will require baffles or expensive flushing arrangements, while a longer, thinner basin will be unnecessarily expensive.

Step 5: Determine the basin depth so that the average velocity of flow through the basin is between 0.2m/s and 0.3m/s for the design discharge (Q_d). For sand traps designed under NSIASP, NAD, a trapezoidal settling basin is recommended with side slopes of 1V: 1H or 1V or 1.5H, with the flushing channel being a rectangular flume (see Figure 4.4). If the width of the basin is large, for more effective flushing provision of two or more settling basins separated by divide wall(s) is recommended. Gates are required so that each basin can be flushed in turn.

Figure 4-3: Single (L) and double (R) basin sand trap looking d/s (under construction)

According to GTZ Publication by Helmut Lauterjung & Gangolf Schmidt, 1989, Planning of Water intake structures for irrigation or hydropower:

Suspended matter concentration, C = m/V …..…………………..……………………………… (4-8)

Where, m is weight of suspended matter, kg and
V is volume of water, m^3

Average suspended matter concentrations (C) are generally:

- C = 0.1 to 1.0 kg/m³, in lowland rivers
- C = 2.0 to 10 kg/m³ in mountainous rivers/brooks.

However, according to nature of catchment areas (i.e. topography, geology, land use, vegetation), these values can be far exceeded or not reached. For example, the suspended matter concentration in the lower course of the Yellow River in China varies seasonally between 60 and 600 kg/m³.

4.4.3 Design of sand trap under flushing conditions

Step 1: Design parameters

The flushing discharge is usually set at 1.2 Q_d where Q_d is the design discharge for the intake.
Various recommendations are given for the flushing velocity. For example the GoI Irrigation Design Manual, December 1986 recommends a flushing velocity of 1.5m/s and a Froude number (Fr = v/(g*y)^$^{0.5}$) of less than 1. Supercritical flow is therefore avoided.

In contrast, Varshney & Gupter recommend a minimum flushing velocity of 2.0 to 2.5m/s for silt/sand, and 3.0 to 4.0 m/s for boulders. A very (Sediment Control at Intakes) recommends a flushing velocity so that supercritical flow occurs in the sluiceway, i.e. F_r > 1.0.

Sharp transitions in the sluice way should be avoided so that a hydraulic jump does not form until the flow is returned to the river.

Step 2: The width of the flume is the width of the bottom of the trapezoidal settling basin. The slope of the sluice way shall be determined using a uniform flow formula, such as Manning's formula.

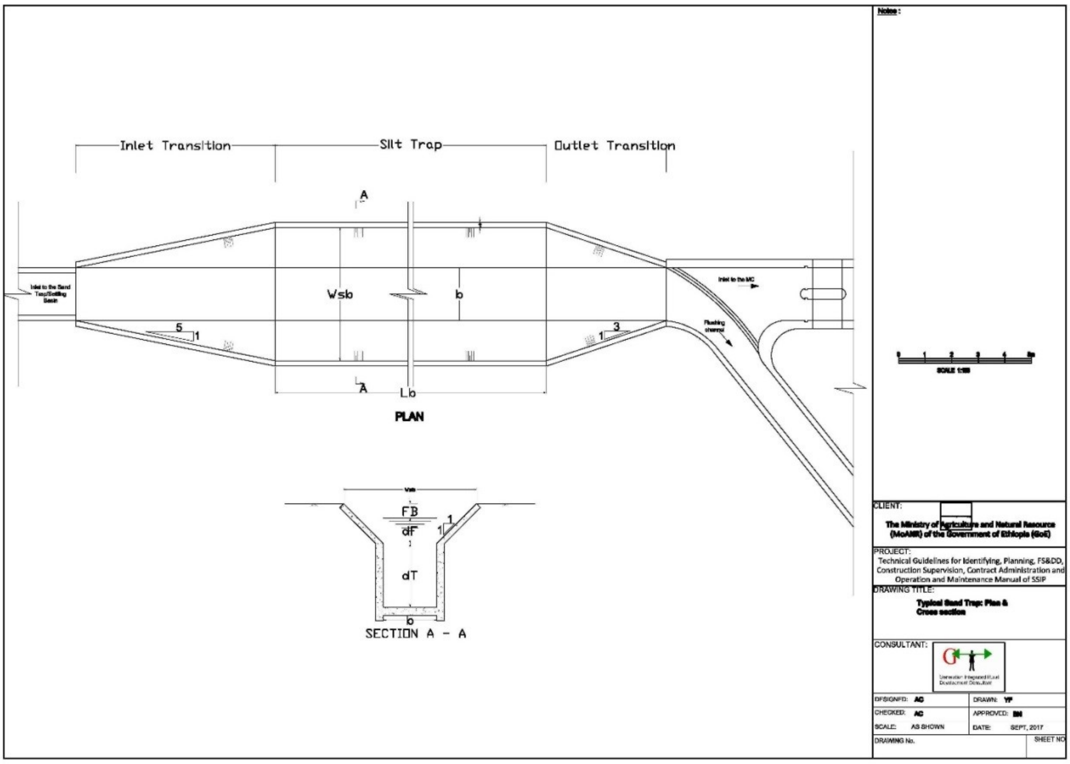


Figure 4-4: Typical sand trap & sluiceway arrangement

4.5 ESCAPE STRUCTURES

These are structures necessary in open canal systems in the event of incorrect operation, gate failure, or other emergency. Either because of gates being wrongly operated upstream or downstream, too much water coming in at the headworks, a blockage downstream, or excess rainwater flooding in during the rainy season, the canal will overflow. On a small canal it may not matter where the overflow takes place. In most cases however, it is desirable to control it so that it can be safely channeled away into the drainage system without damaging crops or canal banks.

Escape structures can be Side escapes, Flushing sluices or Tail escapes.

4.5.1 Side escapes

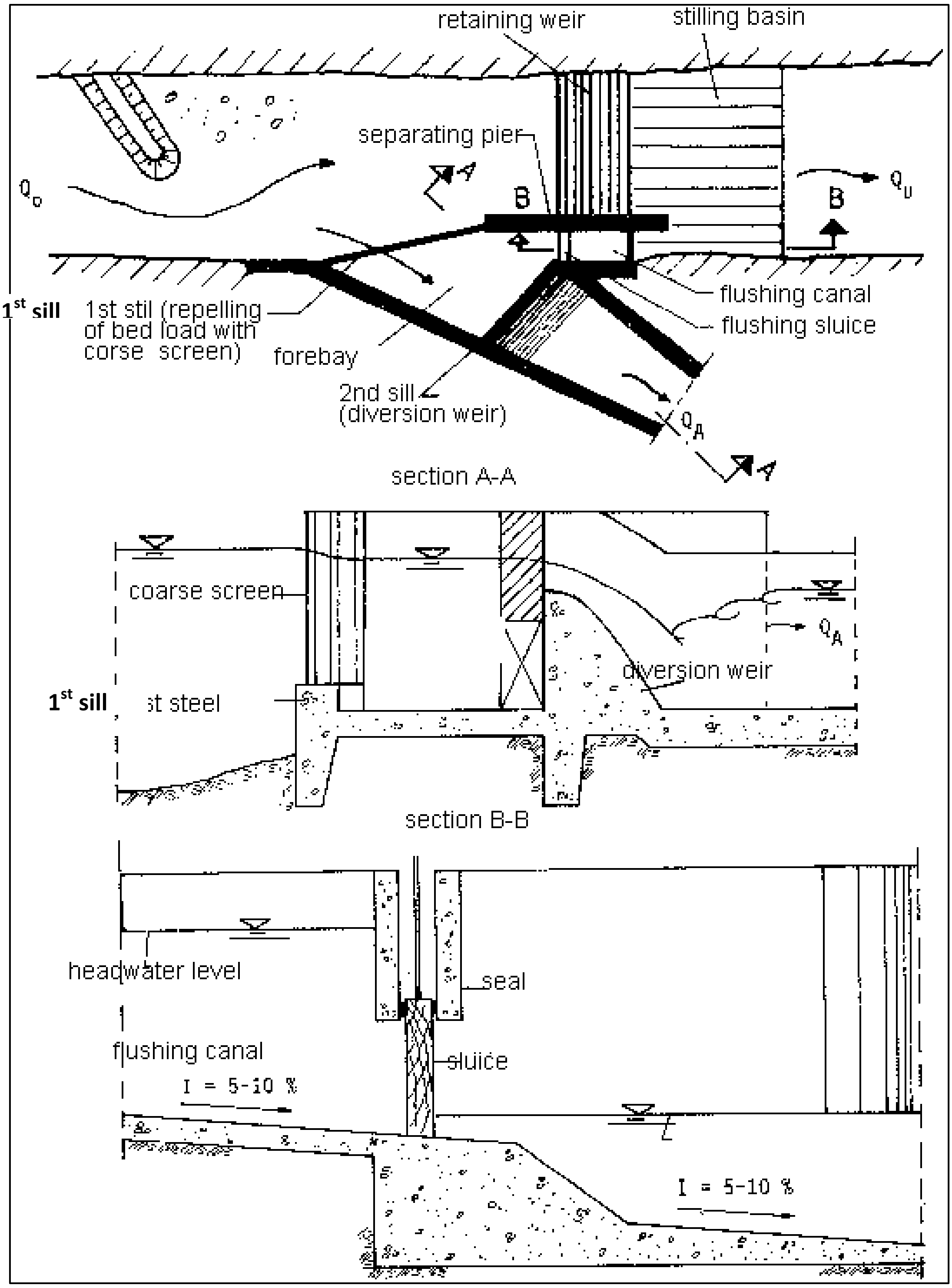
Side escapes comprise a long-crested side weir discharging via a channel or chute into a natural drainage channel. They are located near to or integral with cross-drainage structures, and as close as practicable to potential points of downstream control liable to cause a backwater effect, such as cross regulators. On upstream-controlled canals they would be located on the upstream side of cross regulators. In a downstream-controlled system, they would be on the downstream side.

4.5.2 Flushing sluices

These are escapes with vertical lift undershot gates, which can be used to drain certain reaches of the canal in an emergency such as a breach, or for maintenance. They can be combined with an overspill weir. Such escapes are used in case of sand trap for flushing settled sediment so that the basin would be cleared.

4.5.3 Tail escapes

In an upstream-controlled canal system, tail escapes are required because there is no capability to contain the rejection flow when outlets are closed. They are not required in a canal operated in a mode of downstream control. Tail escapes are normally an over-fall weir incorporating a flushing sluice gate for draining the canal for maintenance.



Source: (GTZ Publication, 1989)

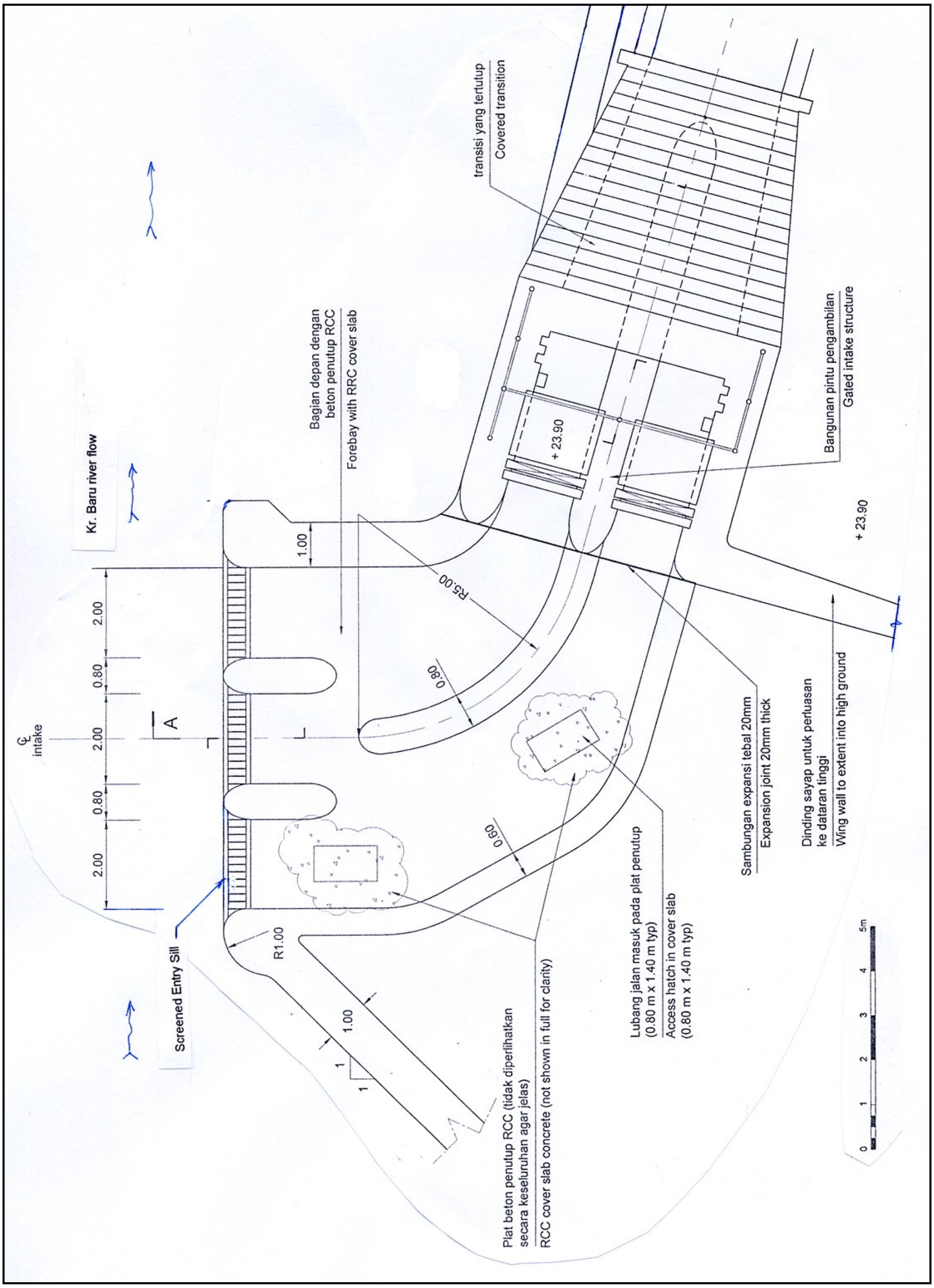
Figure 4-5: Typical dammed Intake & Flushing Canal for Bed Load Removal

REFERENCES

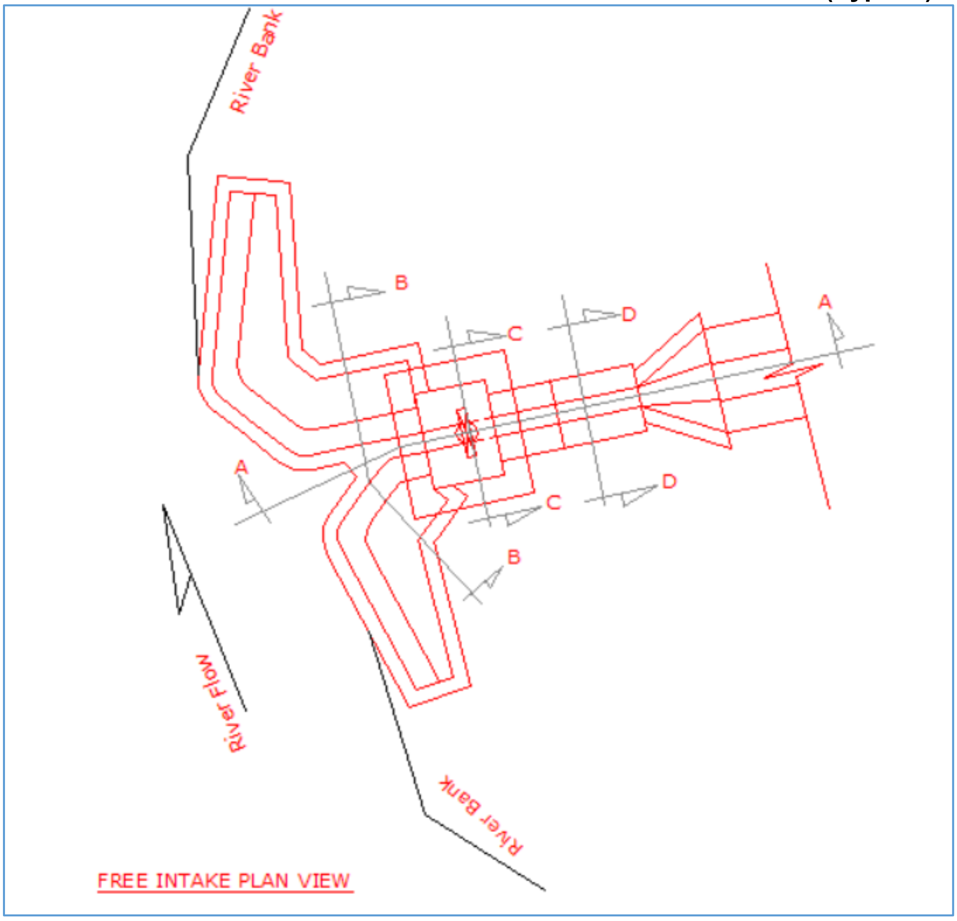
- Avery, 1989, Sediment Control at Intakes – A Design Guide;
- Chow, Ven Te, 1978, Open Channel Hydraulics, Pub. Mc Graw Hill;
- FAO, 2002 "Surface Irrigation Systems: Planning, Design And Maintenance, Module 7: Chapter 6: Hydraulic Structures";
- FAO, 1975 "FAO 26/1- Small Hydraulic Structures";
- FAO, 1975 "FAO 26/2-Small Hydraulic Structures";
- GTZ Publication by Helmut Lauterjung & Gangolf Schmidt, 1989, Planning of Water intake structures for irrigation or hydropower;
- GoI, Irrigation Design Manual, December 1986
- Halcrow Group Ltd, 2004, Design Manual of Headworks;
- MoANR, 2015 by Generation Integrated Rural Development Consultant (GIRDC), "Training Manual for River Free Intake, Module 5b";
- USBR, 1983, Hydraulic Design of Stilling Basins and Energy Dissipaters.

APPENDICES

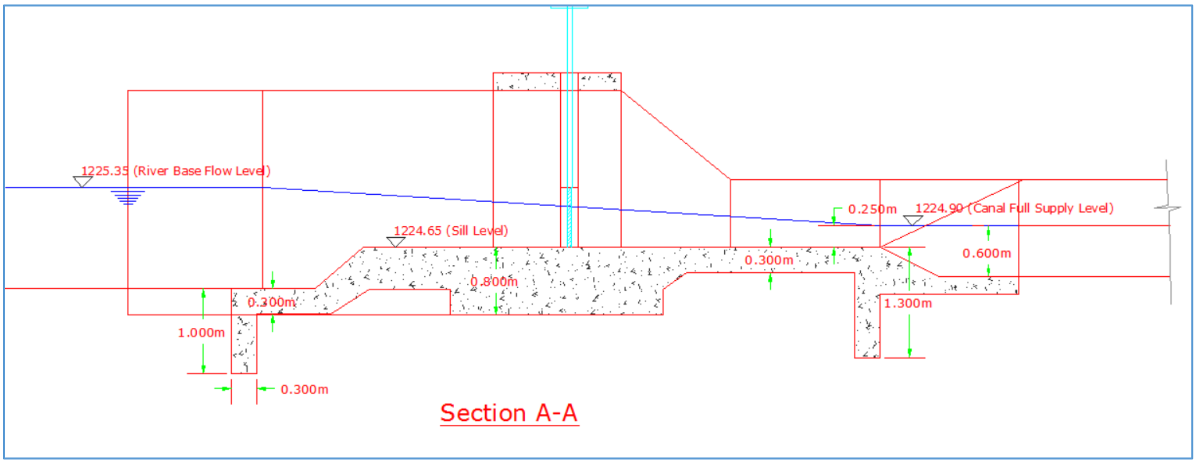
APPENDIX I: Layout of Large Scale Intake Headwork Structure (Typical)



APPENDIX II: Plan & Profile of River Side Free Intake Structure (Typical)

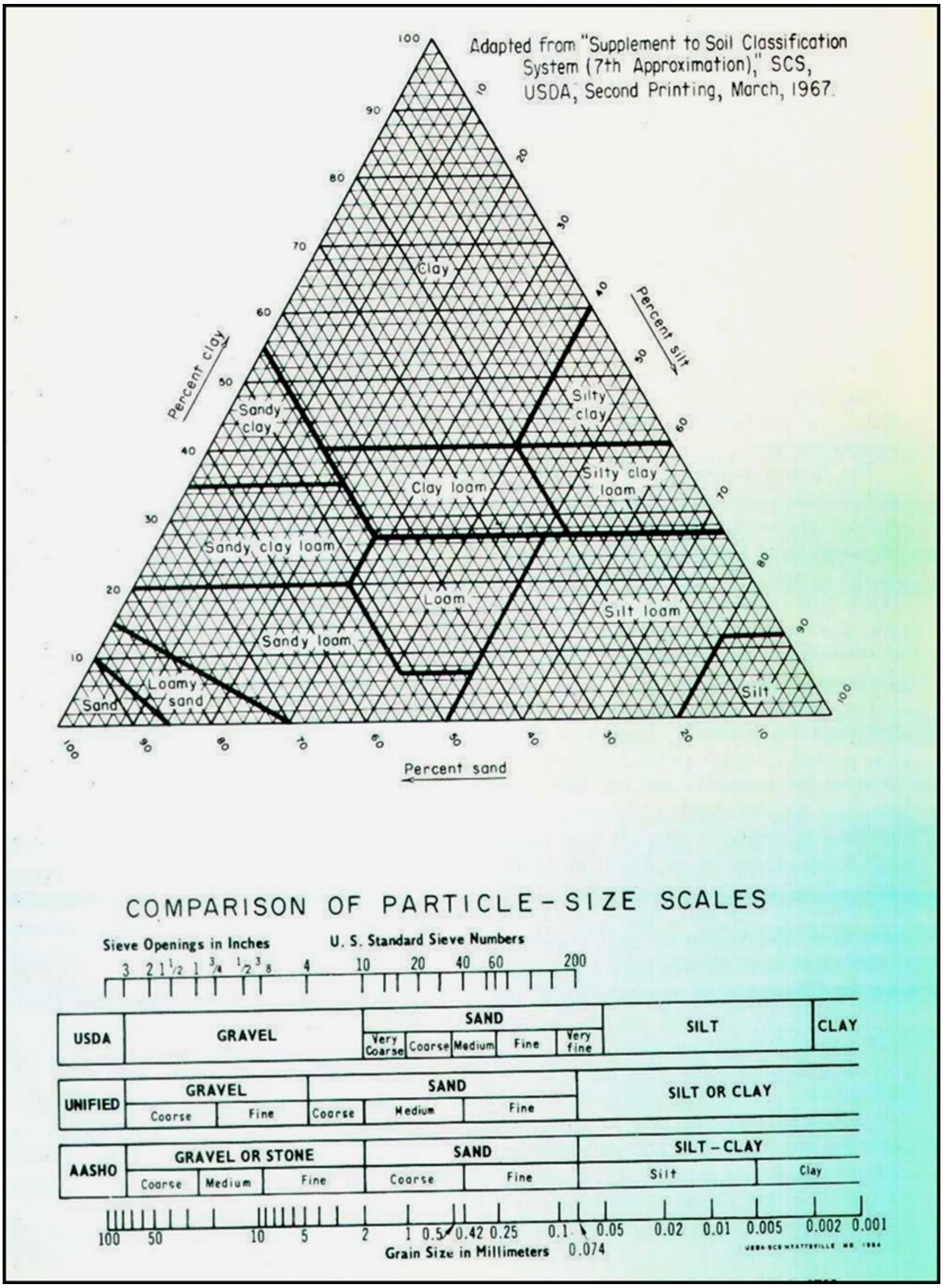


(A) Plan View of Typical Intake Structure



(B) Long Sectional View of Typical Intake Structure

APPENDIX III: Soil Triangle of Basic Soil Textural Classes



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