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Committee J – Reservoir Sedimentation
Workshop « SEDIMENT BYPASSING AND TRANSFER »

SEDIMENT CONNECTIVITY AND SEDIMENT BYPASS DESIGN

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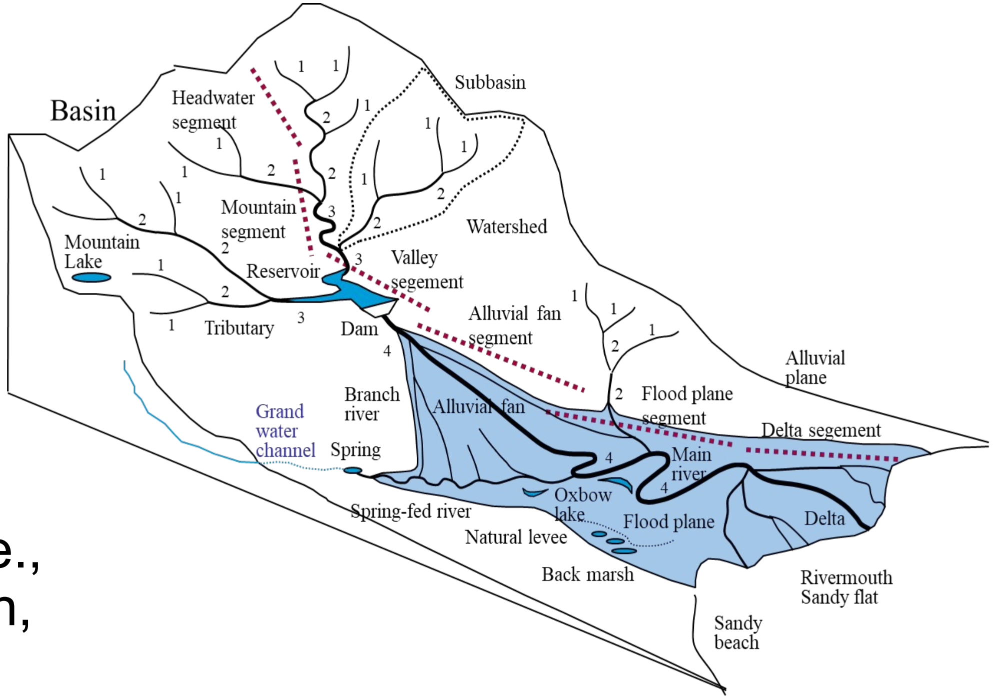
- 3.1. Morphological effects
- 3.2. Ecological effects
  - 3.2.1. Methods
  - 3.2.2. Habitat and invertebrate richness and composition

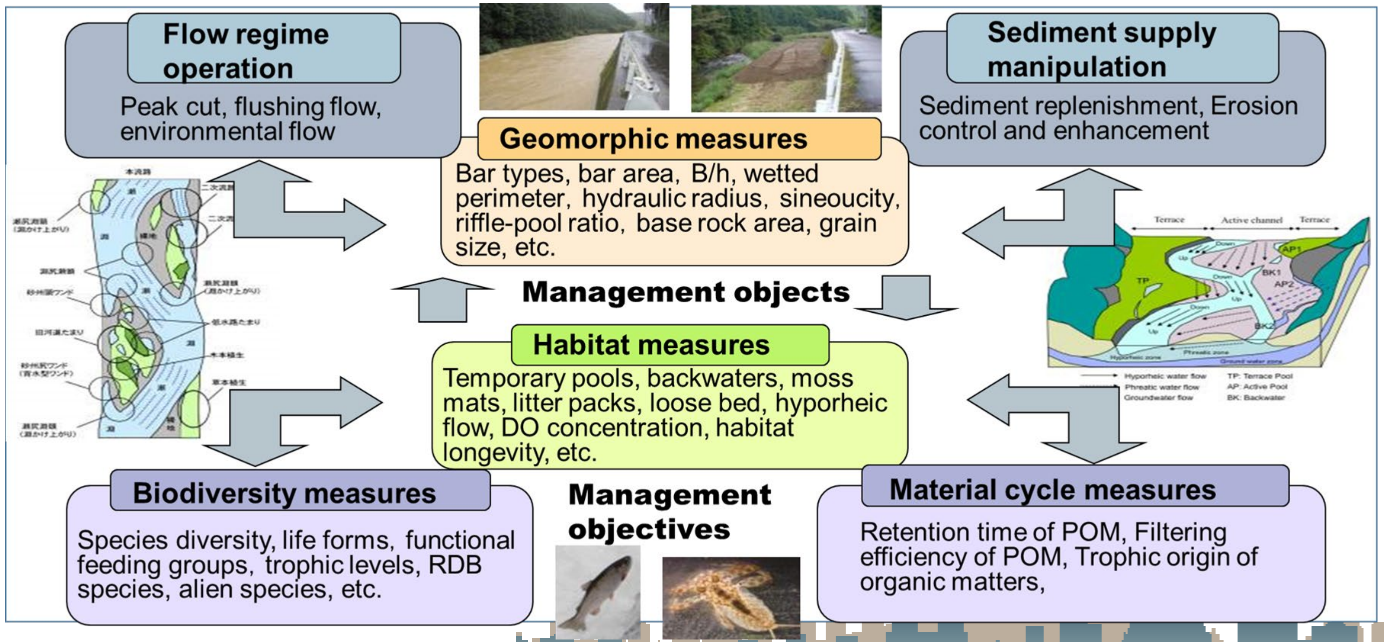
Importance of Sediment Connectivity

- Sediment connectivity :
  - the connected transfer of sediment from a 'source' to a 'sink' in a system via sediment detachment and sediment transport
- Sediment bypass tunnels (SBTs), as well as other bypass and transfer systems, are countermeasures to reduce sedimentation as well as to improve the ecologic state of reaches downstream of dams.
- These systems promote the improvement of both the morphological and ecological effects of downstream reaches.
- In this chapter, both the morphological and ecological effects due to bypass operations (focusing on SBT), i.e., releasing water and sediment to the downstream reach, are discussed.



3.1. MORPHOLOGICAL EFFECTS

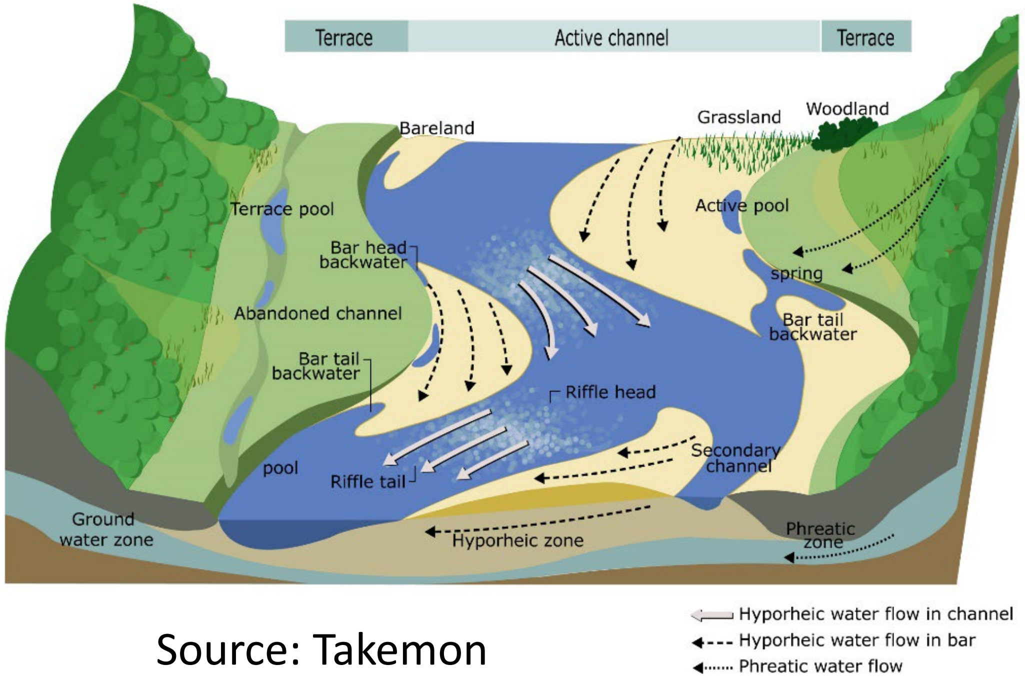
- SBTs allow for conveyance of sediments, both bed and suspended loads, from the upstream river and reservoir to the downstream reach having the potential to enhance river morphology below dams.
- The morphology and ecology of downstream reaches should be monitored to optimize SBT operation not only in regards to the bypassing efficiency but also for effects on fauna and flora.
- The downstream situation should be compared with undisturbed river reaches upstream of the reservoir to assess the ecological effect.



Source: Takemon

3.2. ECOLOGICAL EFFECTS

- Sediment and flow are essential elements of a river ecosystem as they are the basis of aquatic habitats which is required for the life of various organisms.
- Pool-riffle structures is usually associated with gravel bars. They enables species adapted to different flow conditions to coexist in the same reaches. Gravel-bars are also essential for the exchange of water between the surface and the hyporheic zone, a natural process of water purification.
- Bed material size is an important factor in fish and invertebrate species habitats. Different species have different preferences for bed materials according to their mode of existence.
- Generally, species richness and biomass of invertebrates increase with bed particle size from sand to cobbles and decrease from cobbles to bedrock.



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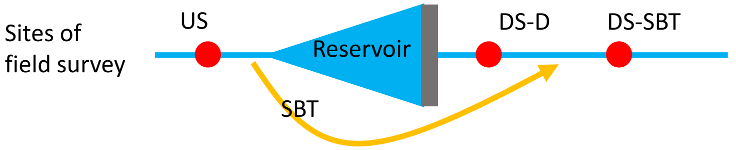
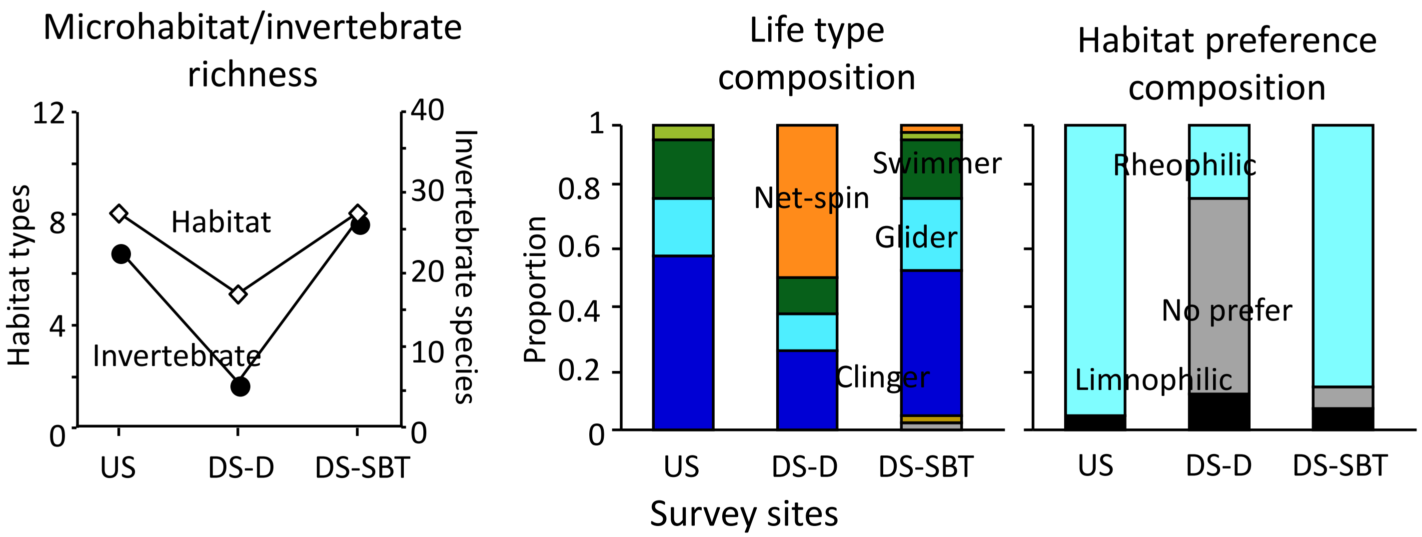
3.2.1. Methods

- To evaluate effects of SBT on fish and invertebrates, field monitoring at different sites including US, DS-D and DS-SBT is recommended.
- US can be assumed as the natural condition. DS-D and DS-SBT are sites without and with sediment supply by the SBT. Effects of an SBT can also be evaluated by monitoring DS-SBT sites for a long period starting from pre-operation of the SBT.
- Channel characteristics such as bed slope, channel width, and GSD on the bed surface should be surveyed as boundary conditions at each site. Topographic surveys that allow evaluation of the size of gravel bars and the dominance of pools and riffles in the reach of interest would help discussing relationships between sediment conditions and biological features.
- The space-for-time substitution approach in which downstream changes in morphology following SBT operation are evaluated by comparing various reaches (at different dams) on the basis of years following SBT initiation.



3.2.2. Habitat and invertebrate richness and composition

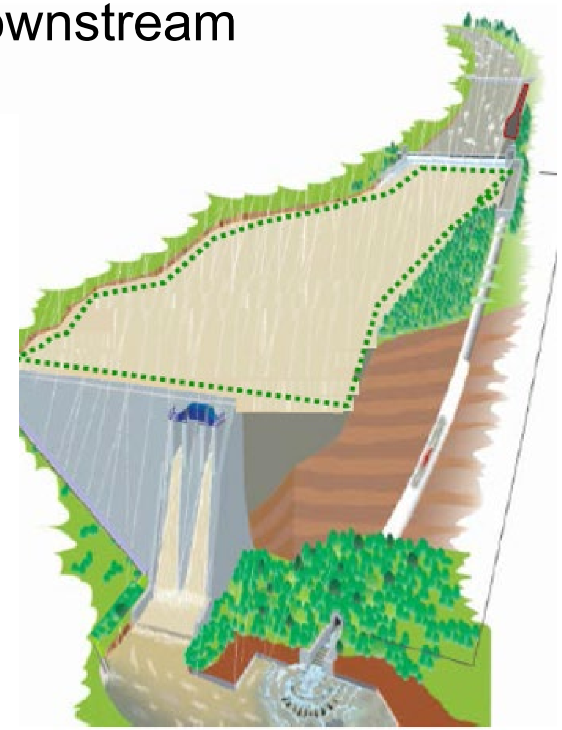
- As indices of the ecological status of ecosystems downstream of reservoirs, species richness (number of species), species composition, and similarity index of community can be evaluated for both microhabitats and invertebrates.
- At the Asahi Dam in Japan, with 17 years of SBT operation, microhabitat and invertebrate species richness were higher at US and DS-SBT than at the DS-D.
- The species composition at DS-D was clearly dominated by net-spinners (that prefer a stable bed) and limnophilics (pool specialists), while the communities at DS-STB and US were much dominated by swimmers, gliders, and clingers (prefer a less stable bed) and rheophilics (riffle specialists) .



- 4.1. Introduction
- 4.2. Bypass Design
  - 4.2.1. Overview
  - 4.2.2. Upstream Diversion Weir
  - 4.2.3. Tunnel Intake
  - 4.2.4. Design Discharge
  - 4.2.5. Tunnel or Channel
  - 4.2.6. Outlet

4.1. INTRODUCTION

- Sediment bypassing around a reservoir is commonly done via a tunnel. However, depending on the topography, open channels may also be used.
- A sediment bypass tunnel (SBT) has the advantage that only newly entrained sediment is diverted to the downstream reach. Previously accumulated sediments in the reservoir are normally not mobilized. The sediment pulse is therefore of natural character, and sediment connectivity is re-established during floods, improving the downstream ecological system (Auel 2018).
- In Japan, SBTs have been studied for a long time. Although this involves a high construction cost, there are many advantages for existing dams (Sumi 2015):
- It typically does not involve draw-down of the reservoir level and therefore does not cause storage capacity loss;
- It has no negative impact on the environment because sediment is discharged during natural flood events.
- SBTs are located mainly in mountainous regions at small- to medium-sized reservoirs (Boes et al. 2019). River bed slopes are normally steep, so that a large volume of coarse material may be transported.

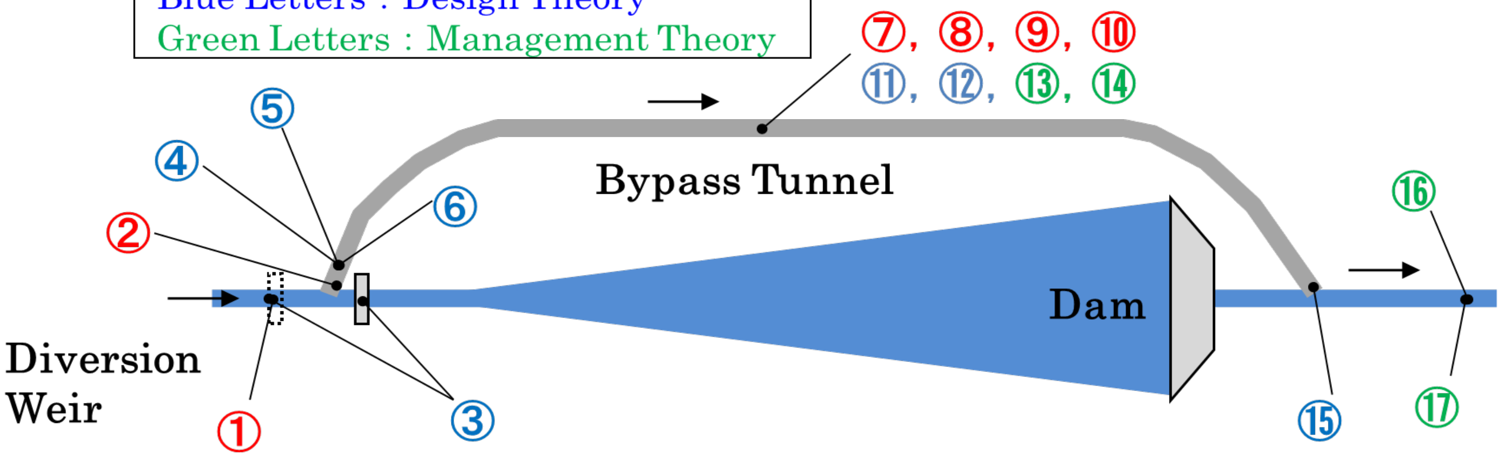


4.2 BYPASS DESIGN

4.2.1. Overview

The committee on reservoir sediment management of the Water Resources Research Center (WEC) in Japan.

Red Letters : Planning Theory
Blue Letters : Design Theory
Green Letters : Management Theory



	Items
1	Facilities for trapping gravel and woody debris
2	Determination of the diversion rule (in case of multipurpose dams including flood control)
3	Construction of the diversion weir and sediment trap weir
4	Measurement of inflow discharge
5	Construction of the tunnel inlet section
6	Abrasion countermeasures of the tunnel inlet section
7	Design discharge of the tunnel

8	Horizontal alignment
9	Vertical alignment
10	Volume and grain size of sediment to be transported
11	Cross sectional shape of the tunnel
12	Abrasion countermeasures of the tunnel
13	Inspection methods
14	Repair methods
15	Construction of the outlet section
16	Monitoring methods for the downstream river
17	Dealing with increased downstream sediment load

Issues at Sediment Bypass Tunnels

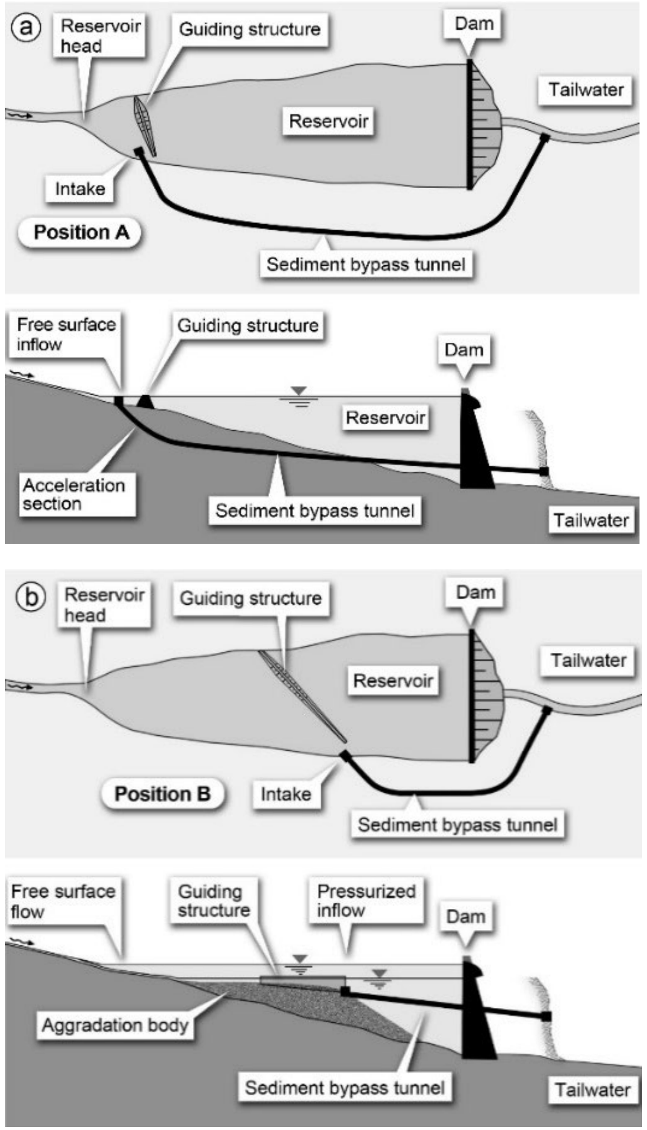
4.2.2. Upstream Diversion Weir

- In general, sediments are entrained from the upstream river and must be guided towards the tunnel intake.
- Some tunnels use upstream check dams to capture the largest bedload fractions (e.g., Koshibu, Japan). These sediments are often used as a construction material.
- Other check dams or guiding structures divert the sediment-laden flow directly towards the bypass intake (e.g., Solis in Switzerland, Asahi and Matsukawa in Japan, Nanhua in Taiwan).

(a) Circular shaped cofferdams with sheet piles as guiding structure into intake at Solis SBT Switzerland (courtesy ewz),
(b) weir as guiding structure at Asahi SBT intake, Ja-pan (courtesy C. Auel)

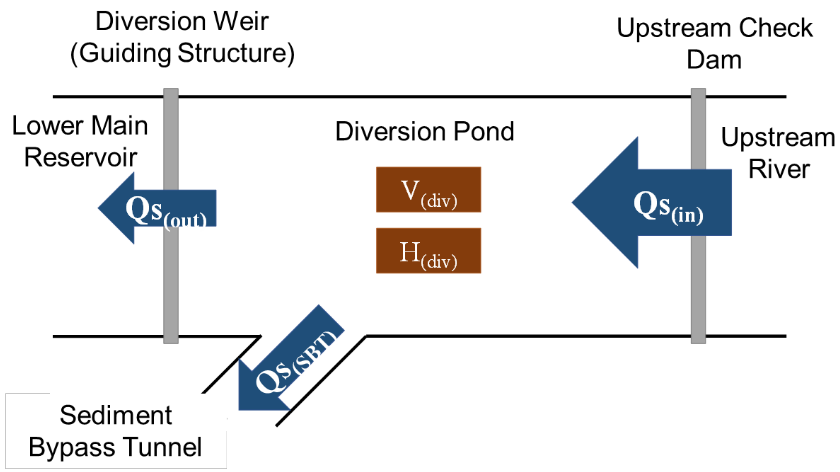
4.2.3. Tunnel Intake

- Two different locations are generally possible. The most common location for the bypass intake is at the reservoir head (a). Another suitable intake location is further downstream closer to the dam (b) (Auel and Boes 2011).
- (a) The advantages of an intake at the reservoir head:
  - (I) The entire reservoir is kept free from sediment
  - (II) The reservoir level during bypass operation is independent from the upstream river reach and can be kept at full supply level
  - Disadvantages are, depending on the topography, the long distance from the reservoir head to the tailwater causing high tunnel construction costs, and the free-surface flow conditions at the tunnel intake requiring a steep acceleration section.
- (b) The advantages of an intake at the further downstream:
  - (I) The distance between the tunnel intake and the tailwater is short, reducing tunneling costs
  - (II) The intake inflow is pressurized, with no need for a steep acceleration section.



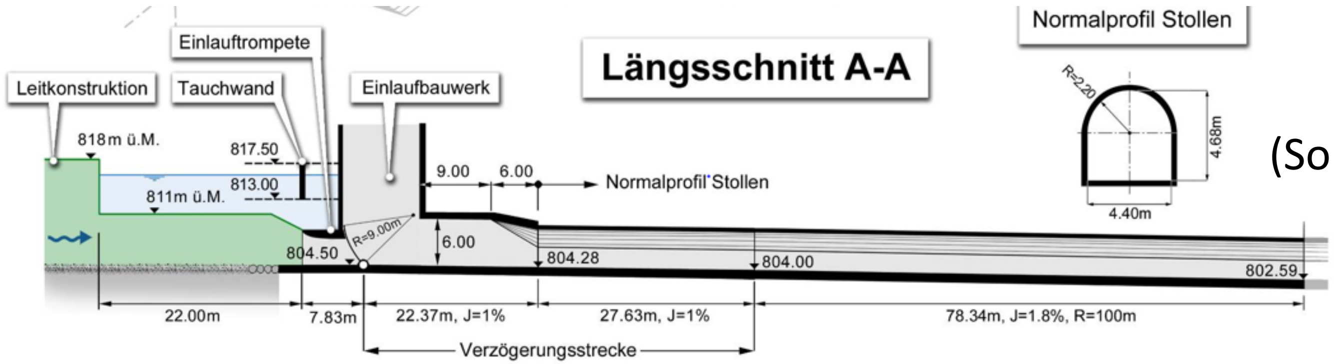
4.2.4. Design Discharge

- The choice of the SBT discharge capacity depends on an economic tunnel cross-sectional area and on the hydrological catchment conditions.
- The surplus flow exceeding the SBT discharge capacity must be conveyed to the downstream main reservoir. Because routing of all incoming sediments is achieved only up to the SBT with a design discharge of high flood return period.
- Absolute values of SBT design discharges currently in service or under construction range from 40 to 400 m3/s. Higher capacities of 1000 m3/s are found in Taiwan. These intake structures are located within the reservoir and are always submerged which may be classified as sediment venting tunnels.
- The duration of SBT operation ranges from 1 day/year to more than 100 days/year, depending on local hydrology and reservoir size. The median operating duration of SBTs is five to six days/year (Müller-Hagmann, 2017).
- A guide structure that is high enough could allow coarse sediments to deposit in the upper reach of the reservoir. These would be then removed towards the SBT once the flow decreases and turns back to free flow at the intake. In this case, only the fine sediments that overflow the wall will deposit in the lower main reservoir.



4.2.5. Tunnel or Channel

- The conveyance of the sediment-laden flows is achieved via the tunnel (and/or channel). Downstream of the gate, the discharge accelerates to generate supercritical flow conditions which is achieved by a steep acceleration section.
- If the intake gate is located further downstream, the tunnel invert level can be situated lower than the river bed or the surrounding aggradation body, respectively. The resulting energy head leads to pressurized inflow conditions, but downstream of the gate, supercritical open channel flow typically occurs.
- The tunnel cross section of most SBTs is of archway/hood or horse-shoe shape. Circular ones are rare as the sediment transport is concentrated at the lower invert and there is the challenging trafficability during construction and maintenance.
- The slope needs to be steep enough to generate enough bed shear stress to transport all incoming sediments into the tailwater without depositing.



(Source, EWZ)

(Source, MLIT)

4.2.6. Outlet

- The outlet structure discharges the sediment to the tailwater downstream.
- Sufficiently high transport capacity in the downstream river reach must be secured to avoid sedimentation and bed aggradation in the outlet and further downstream. Usually, this should be no problem as the sediment transport process in the entire river system is revitalized to its original condition.
- A sudden sediment pulse from the tunnel operation may temporarily exceed the natural transport capacity of the river. The tunnel outlet should not release any sediments near the dam to avoid sedimentation and backwater effects that may interfere with outlets.
- A drop from the tunnel outlet to the river reach should be designed to avoid backward deposition in the tunnel itself. Scouring due to outlet jet impingement needs to be considered and avoided.
- Additionally, the angle between the tunnel centerline and the river thalweg should be kept small to reduce erosion impact on the opposite river shore.

Solis SBT
(Source, Boes)

Asahi SBT