NOAA FISHERIES

West Coast Region

Fish Screening and Guidance at Water Diversions

NOAA Fisheries Service

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FSOC Training, 2023

Topics

- Biological Basis for Design
- Diversion Type Selection
- Entrance Conditions
- Screen Sizing
- Screen Material
- Screen Type Selection
- Cleaning System
- Bypass Systems
- Special Conditions & Other Topics

- Guiding Principles of Fish Screening:
  - Screening criteria are conservative in nature, providing protection for the weakest species at most vulnerable life stage under adverse environmental conditions
  - Screening criteria rely on volitional guidance wherever possible.

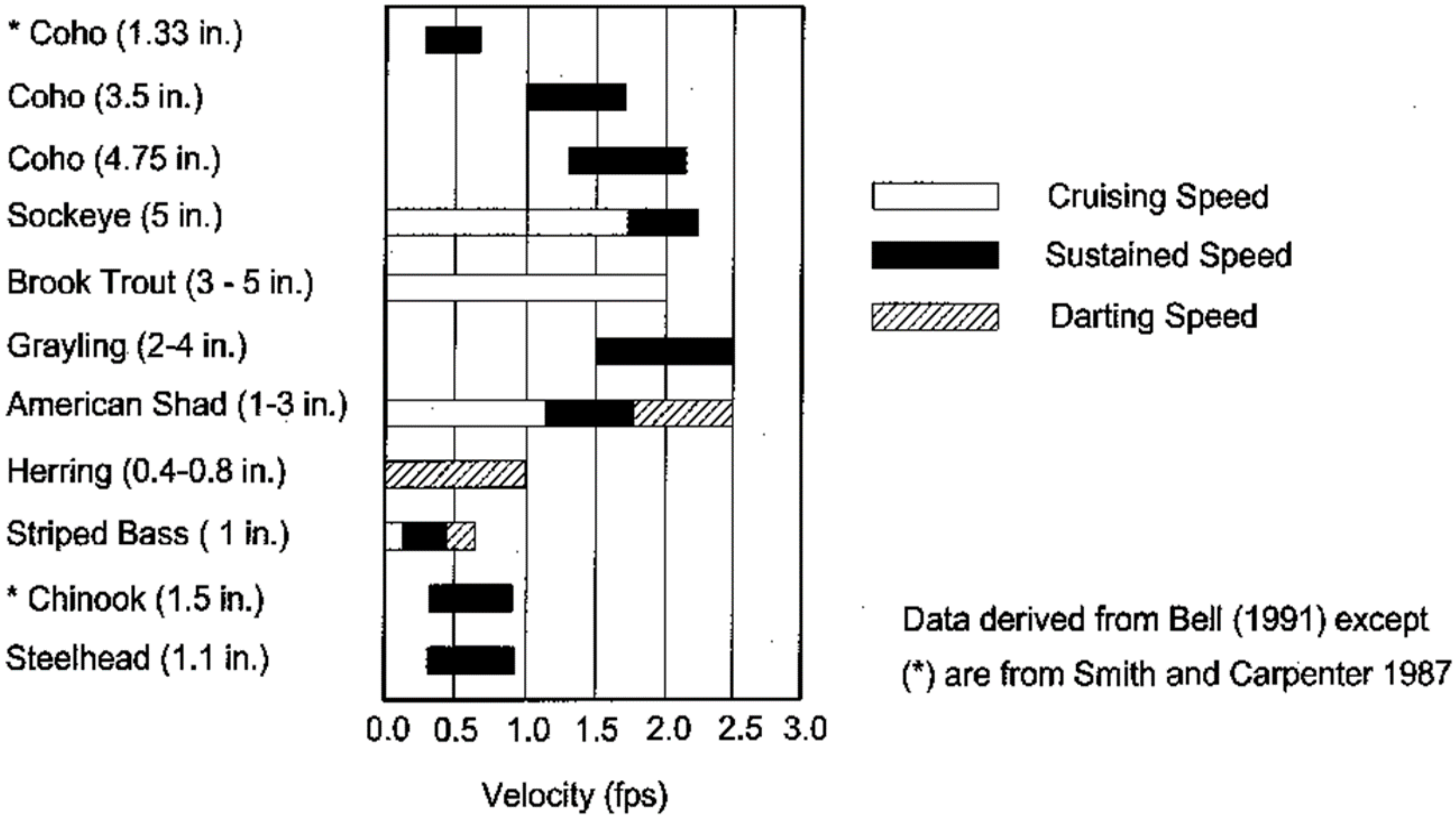
Biological Basis for Design

Juvenile Salmonid

Fish Screening Biology and Behavior

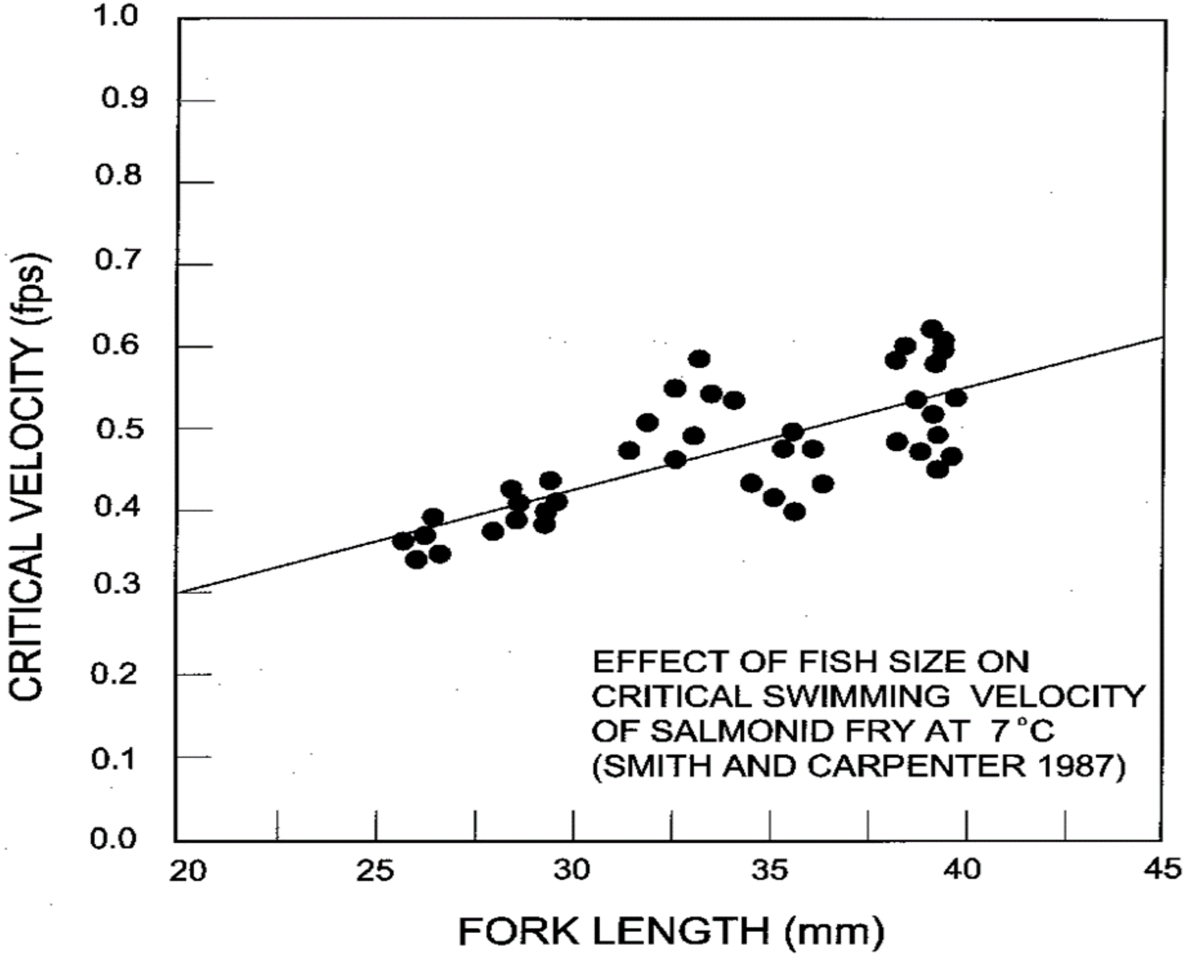
- Swimming abilities
- Fish size
  - Drives requirements for mesh openings
- Rejection/Delay
  - Velocity Changes
  - Lighting Changes
  - Turbulence
  - Changes in hydraulic regime

Juvenile Fish Swimming Speeds

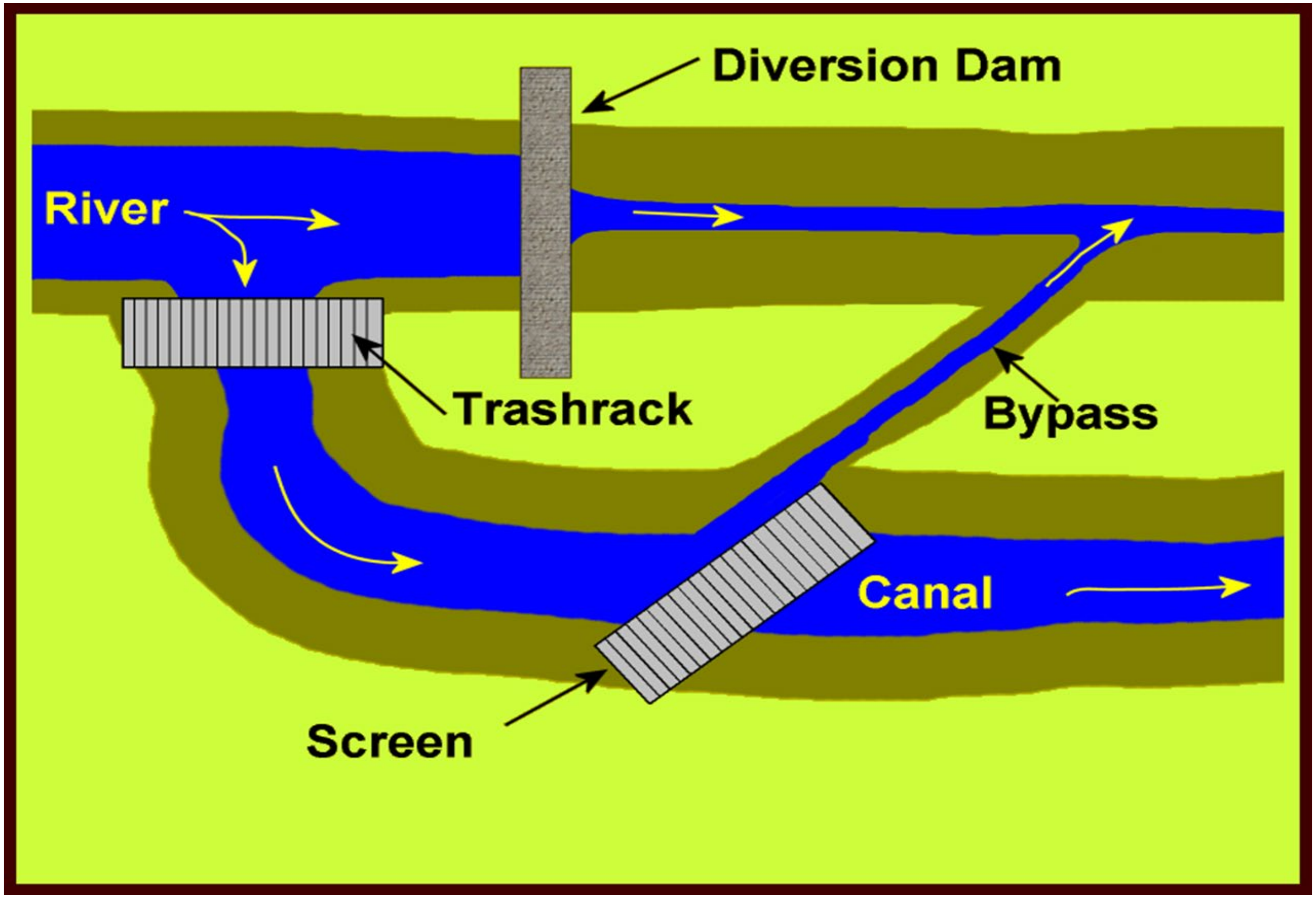


Data derived from Bell (1991) except
(*) are from Smith and Carpenter 1987

Effect of Fish Size on Critical Velocity

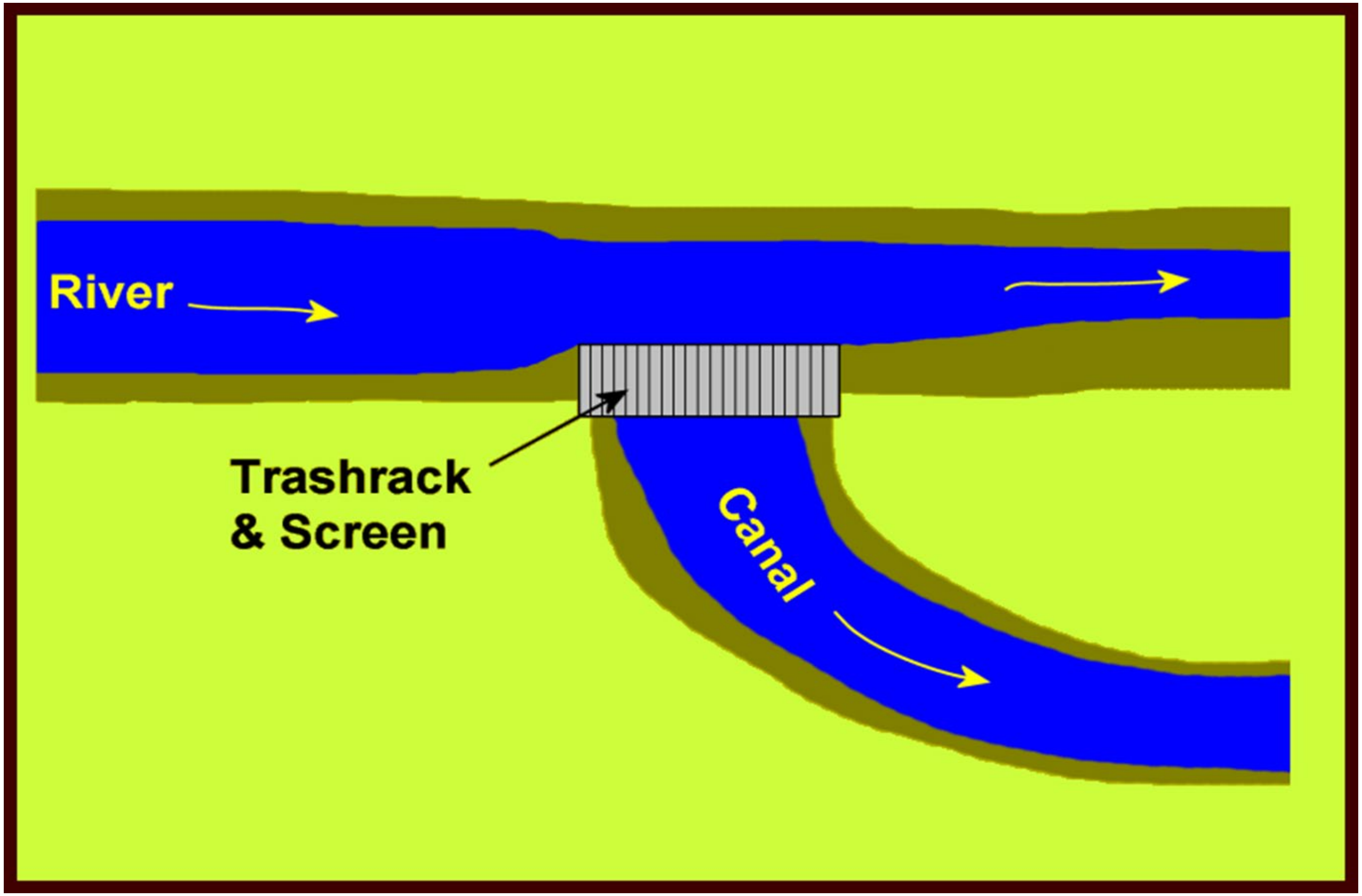


Diversion Type Selection



Off Channel Screen

Diversion Type Selection



On Channel Screen

Diversion Type Selection

Considerations:

- Diversion canal as fish habitat
  - Good or bad.
  - May also be predator habitat
- Diversion operations – pitfalls
- Starting and stopping of diversions
- River-reach de-watering between POD and bypass return
- River Banks Profile
  - Very flat banks not conducive to on channel screens

Entrance Conditions and Screen Orientation

Trash Racks

- Off channel intakes shall include a trash rack which shall be kept free of debris.
- In certain cases, a satisfactory profile bar screen can substitute for a trash rack.
- Trash rack should be easily cleaned to prevent clogging and potential injury.
- Trash rack bar spacing set by based on species and life-stage present in system
    - If adults can swim up through bypass, size trash rack accordingly

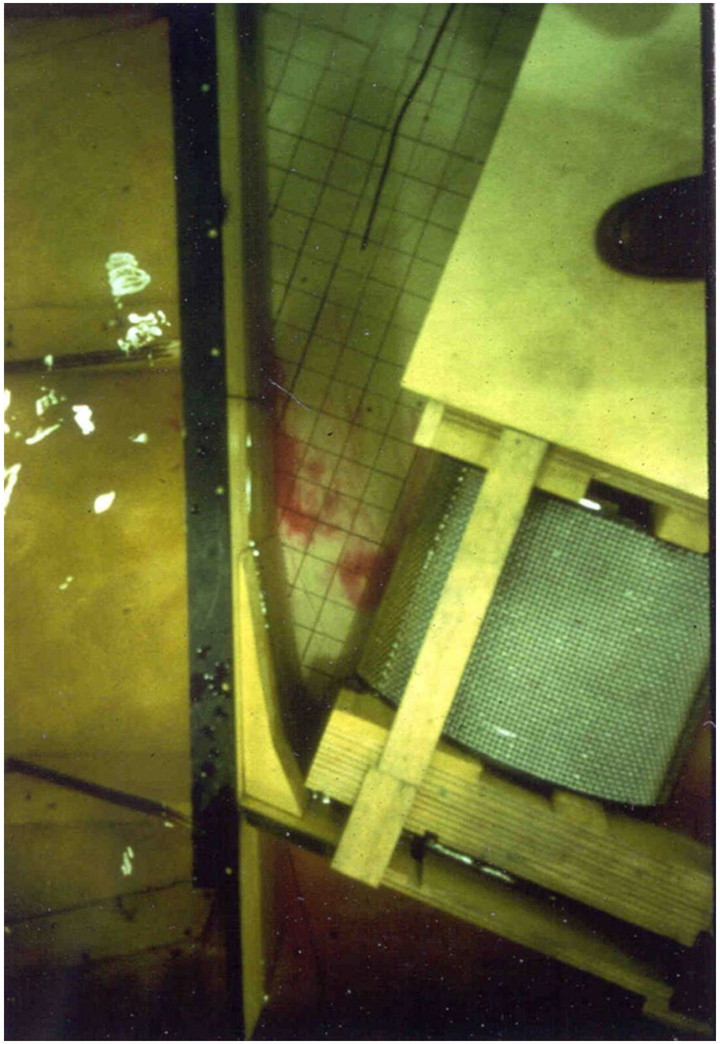
Entrance Conditions and Screen Orientation

Trash Racks, Cont.

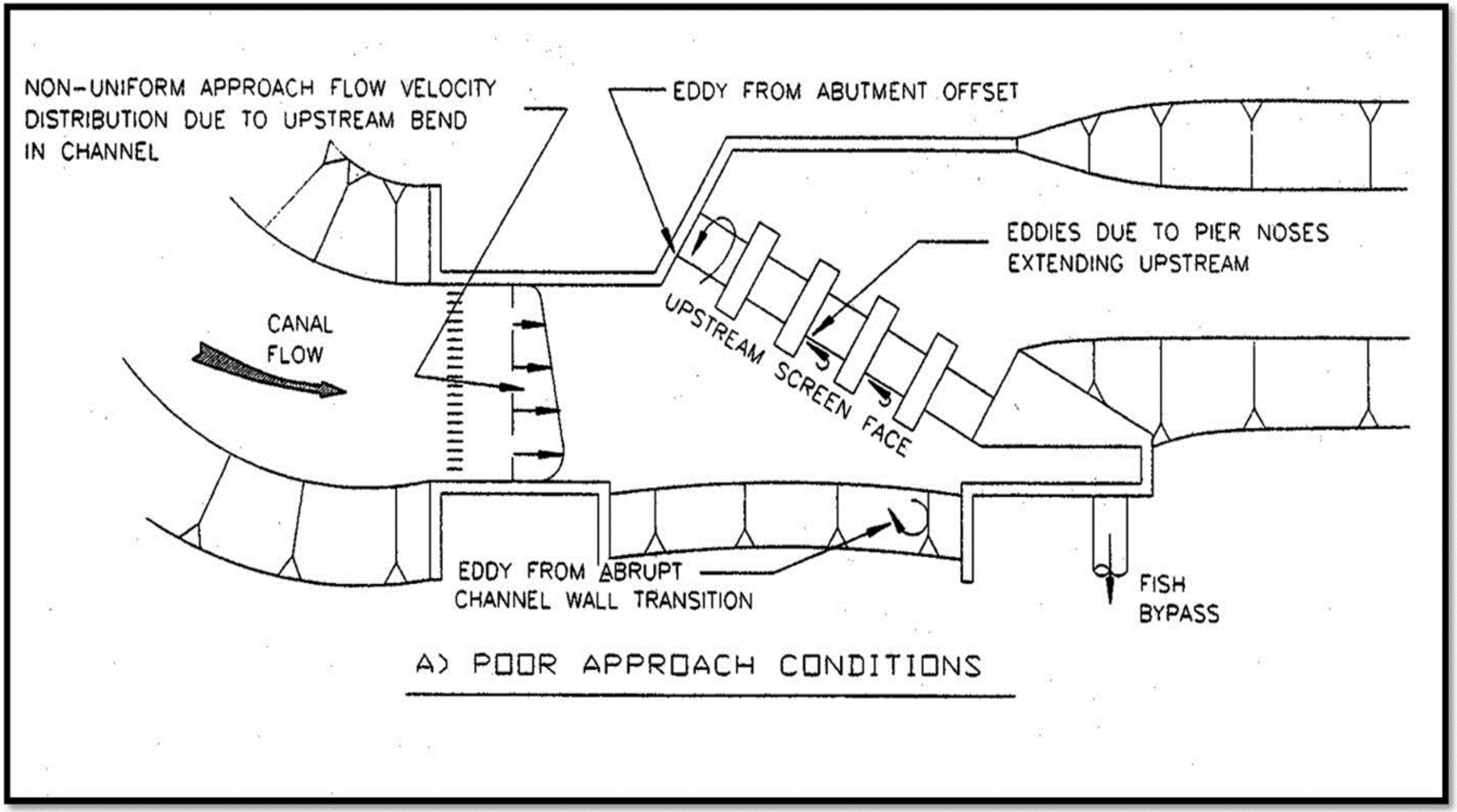
- In some cases, on channel T-screens or Cone screens should be equipped with trash racks.
- If trash racks will experience high sweeping velocities, consider setting bars with small amount of separation angle to prevent debris entrapment.

Entrance Conditions and Screen Orientation

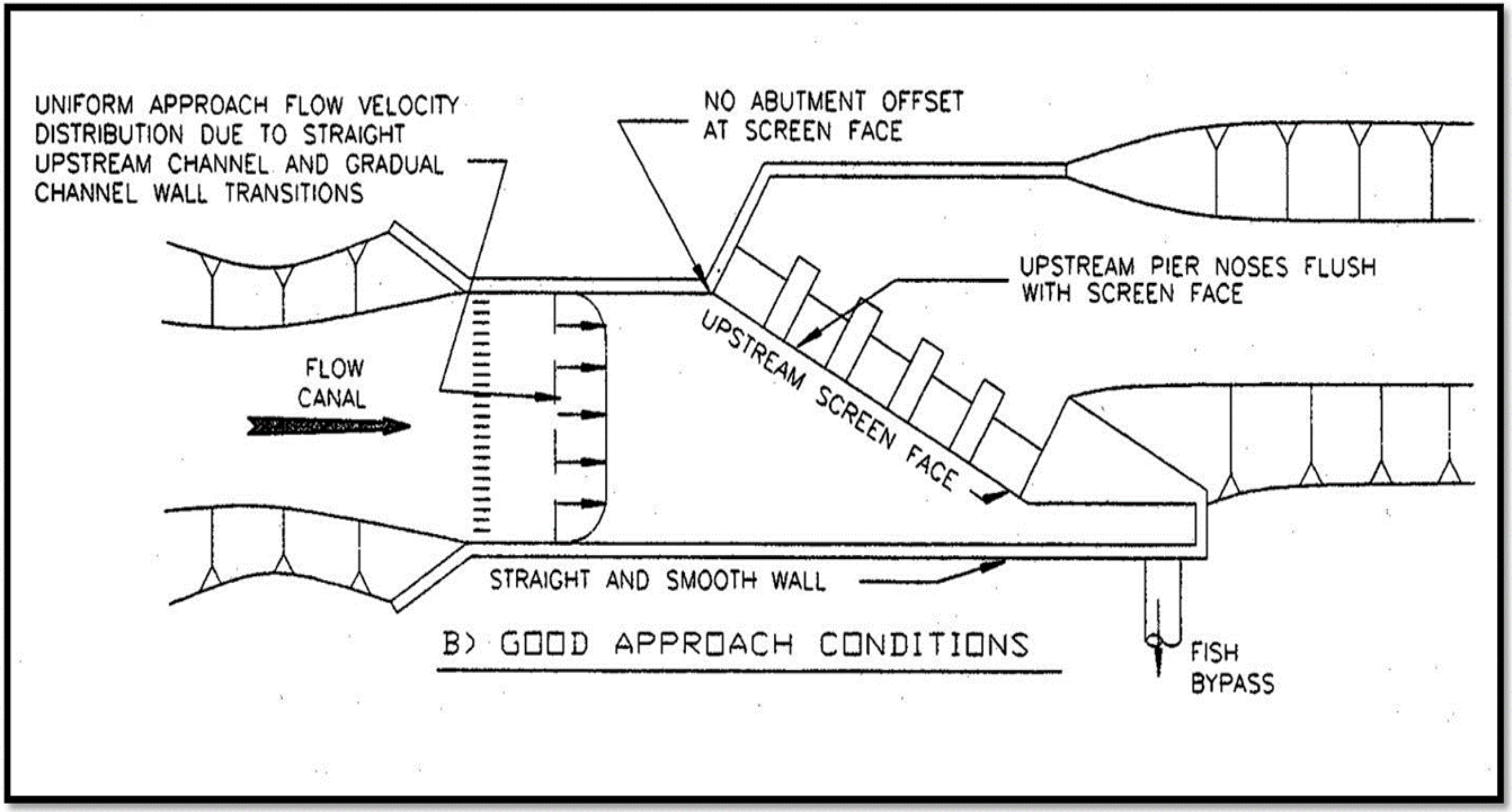
Entrance Conditions and Screen Orientation



Entrance Conditions and Screen Orientation



Entrance Conditions and Screen Orientation

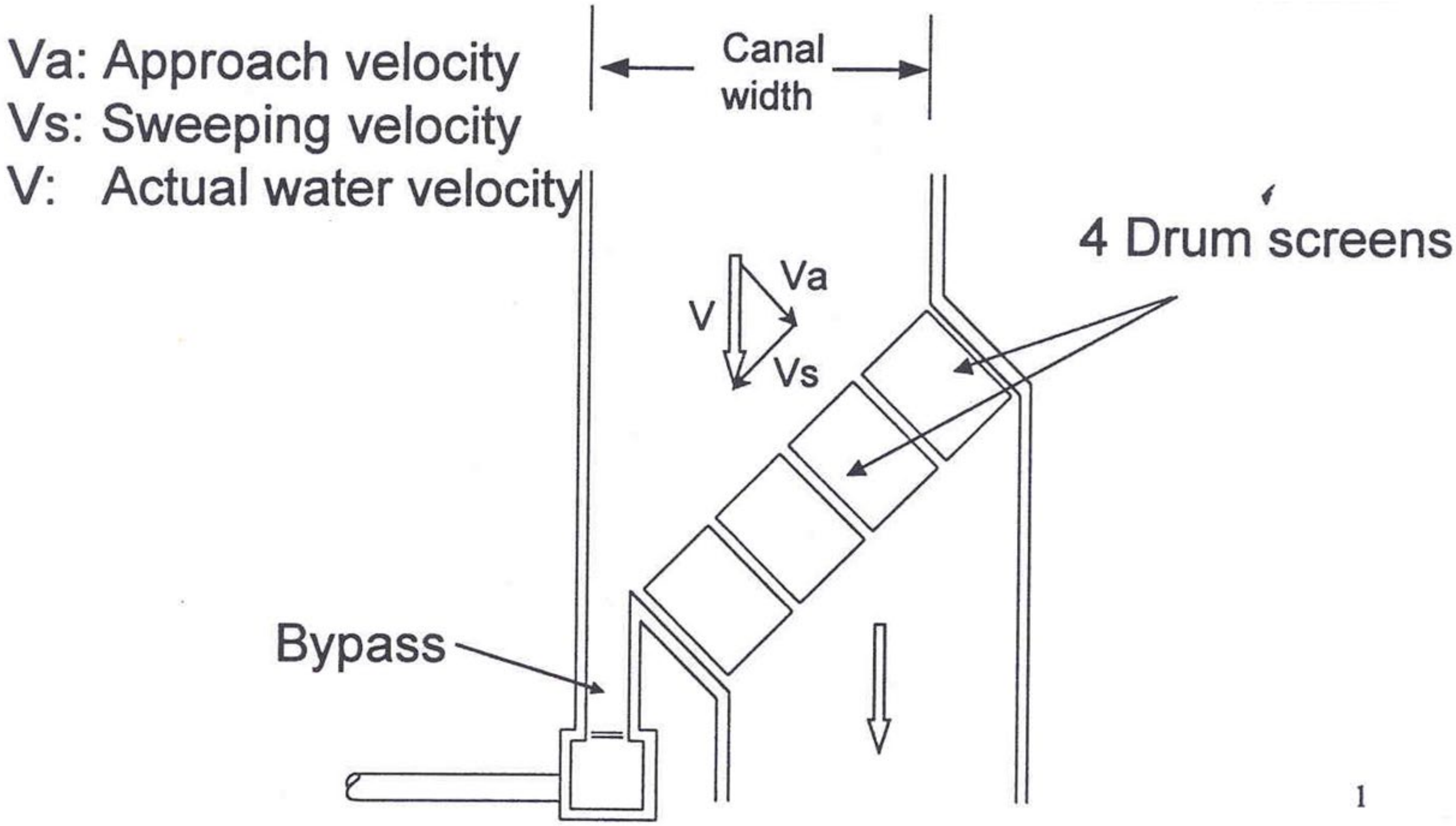


Entrance Conditions and Screen Orientation

Screens longer than 6 feet:

- Must be angled
- Sweeping velocity must be greater than approach velocity
- Sweeping velocity may not decrease along screen length

Screen Sizing



Screen Sizing

Screen Size Dictated by Approach Velocity Criteria

- Approach Velocity <0.4 feet per second for active screens
- Approach Velocity <0.2 feet per second for passive screens*
- A=Q/V
- Important to realize that approach velocity does not equal “pore velocity”-common error
- For conventional rotary drum screens, area is calculated with vertical projection, not wetted perimeter
  - Difficult for fish to escape from marginal areas at top and bottom of drum screen

Screen Sizing

Some controversy over what flow to size screen to…

- Default is to size to water right.
- Less than water right?
    - Has the full water right ever been diverted?
- Greater than water right?
    - Does the irrigator currently divert more than water right?
        - Pragmatism vs Idealism
    - Future build-out for municipal screens.

Sweeping Velocity

- Sweeping Velocity
  - Component of velocity that moves fish past screen into bypass (if equipped)
  - Must be greater than approach velocity.
  - Ideally, for longer screens, should be between 0.8 and 3.0 feet per second.
    - Goes back to volitional guidance principle.
  - Sweeping velocity may not decrease along length of screen, unless screen is short (< 6 feet long).

Sweeping Velocity

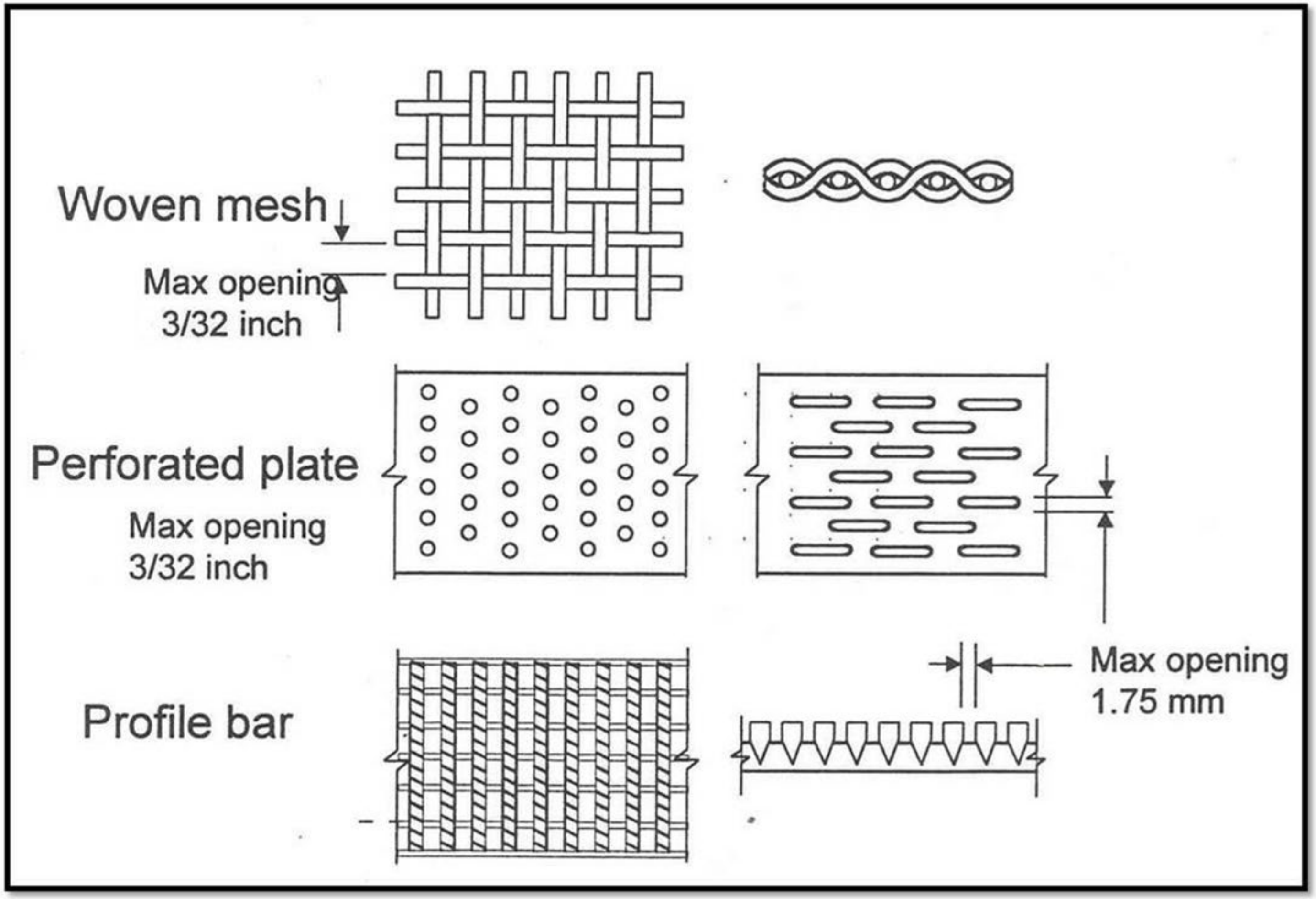
- It should be noted that in on-river diversions, river velocity does not necessarily translate to sweeping velocity.
  - Particularly for large diversions, diverted flow can actually cause river to flow upstream, relative to the screen face.
  - This can be partially remedied with guide walls.

Exposure Time

Sweeping velocity must be able to move fish past entire length of screen within 60 seconds

- If not possible, for canal screens, use multiple entrances to bypass system
- For on river screens, reduced approach velocity of 0.33 feet per second may be acceptable alternative to exposure time criteria
    - Since no bypass system, no option to use multiple entrances

Screen Material

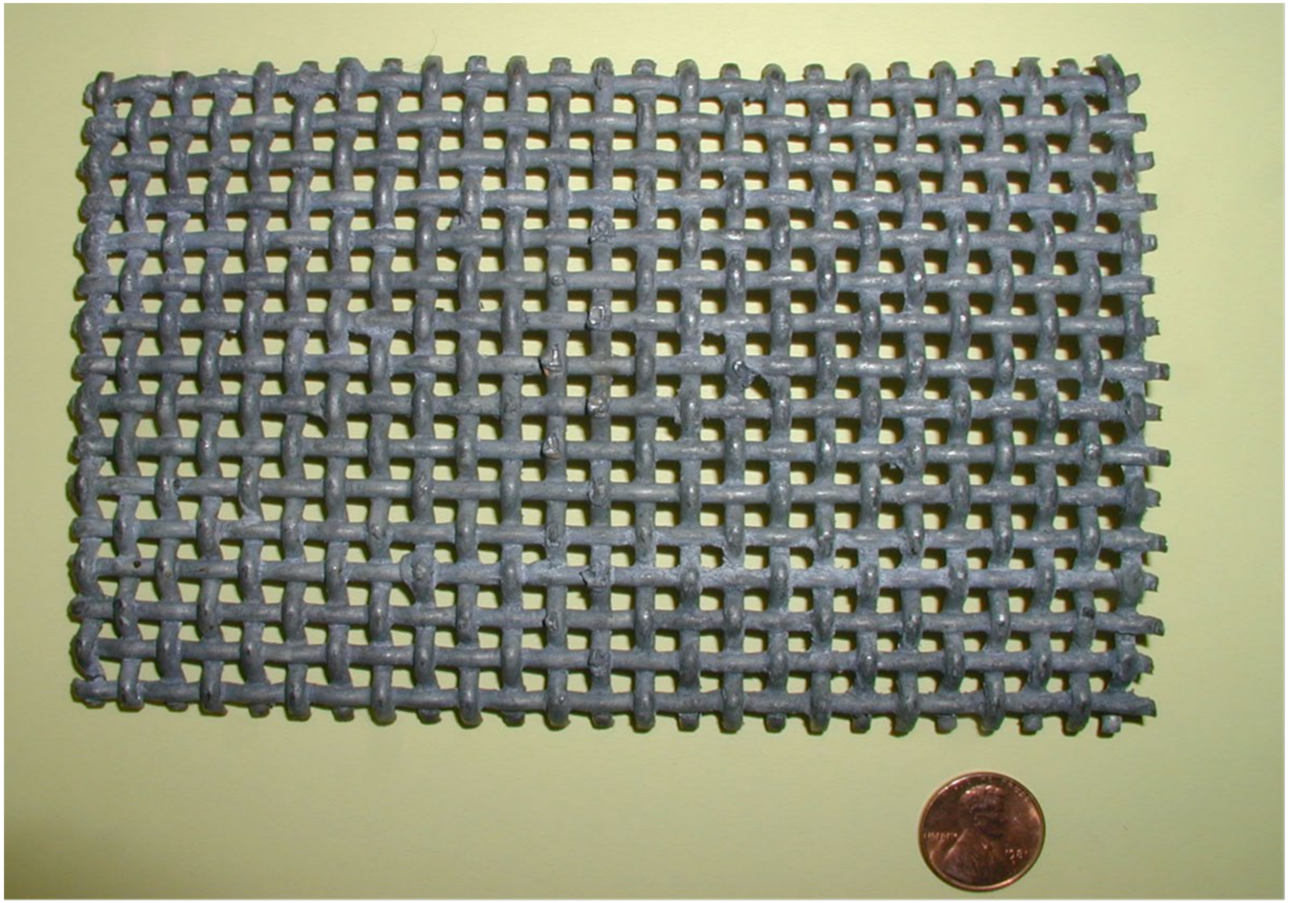


Screen Face Material

Woven Wire Mesh

- Very commonly used screen material
- Wide variety of wire thicknesses and opening sizes.
- Generally aluminum or stainless.
- Criteria:
- Wire gauge:
- 18 gauge fixed panel
- 14 gauge rotary drum
- Max opening: 3/32 inches (measured in diagonal direction)
- Minimum open area: 27%

Screen Face Material

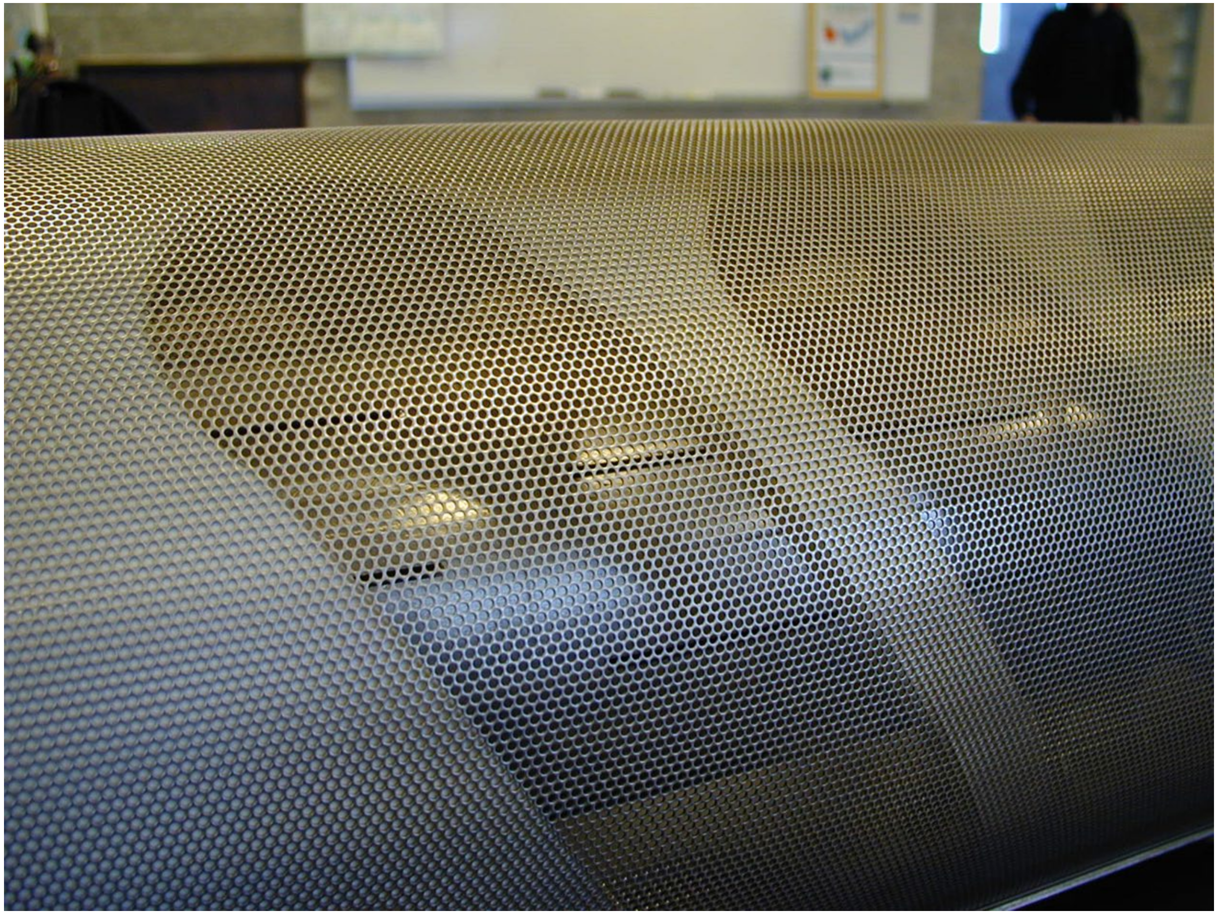


Woven Wire Mesh

Screen Face Material

- Perforated Plate
  - Sheet metal stock punched with an array of holes (round or rectangular).
  - Typically aluminum or stainless steel
  - Easy to work with, relatively inexpensive
  - Criteria:
    - Maximum opening: 3/32 inch
    - Minimum open area: 27%

Screen Face Material



Perforated Plate

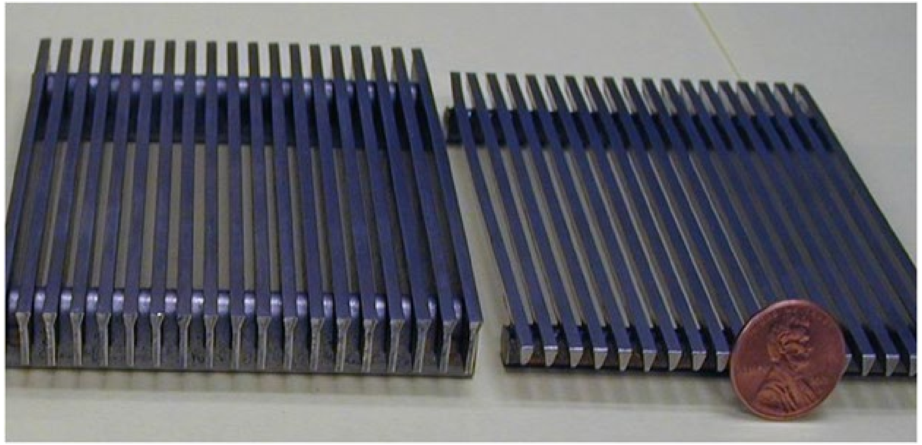
Screen Face Material

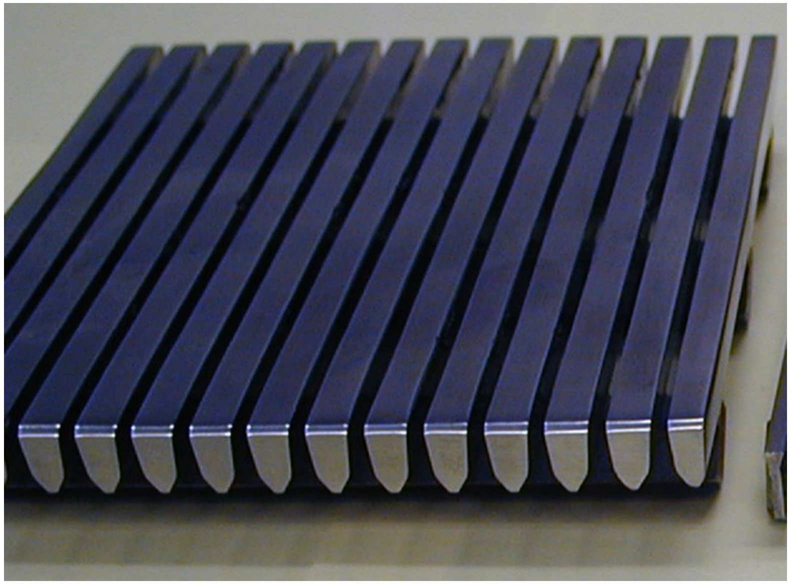
Wedge Wire and Profile Bar Screen Material

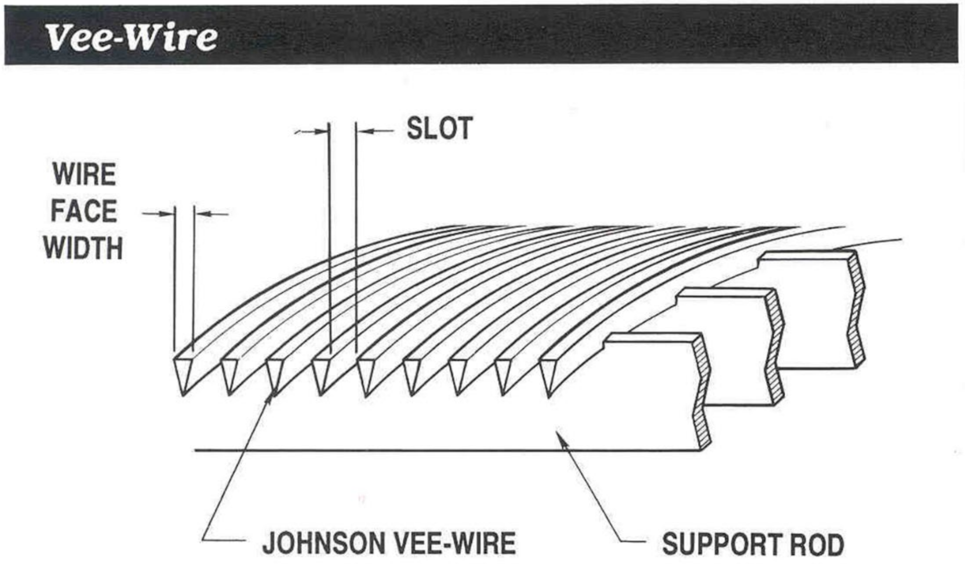
- Stainless steel bars welded to structural backing.
- Common commercial product.
- Expensive material, but cost partially offset by reduced structural cost.
- Bars should be oriented in sweeping direction of cleaning brush.
- Criteria:
  - Maximum opening width: 1.75 mm
  - Minimum open area: 27%

Screen Face Material

Profile Bar







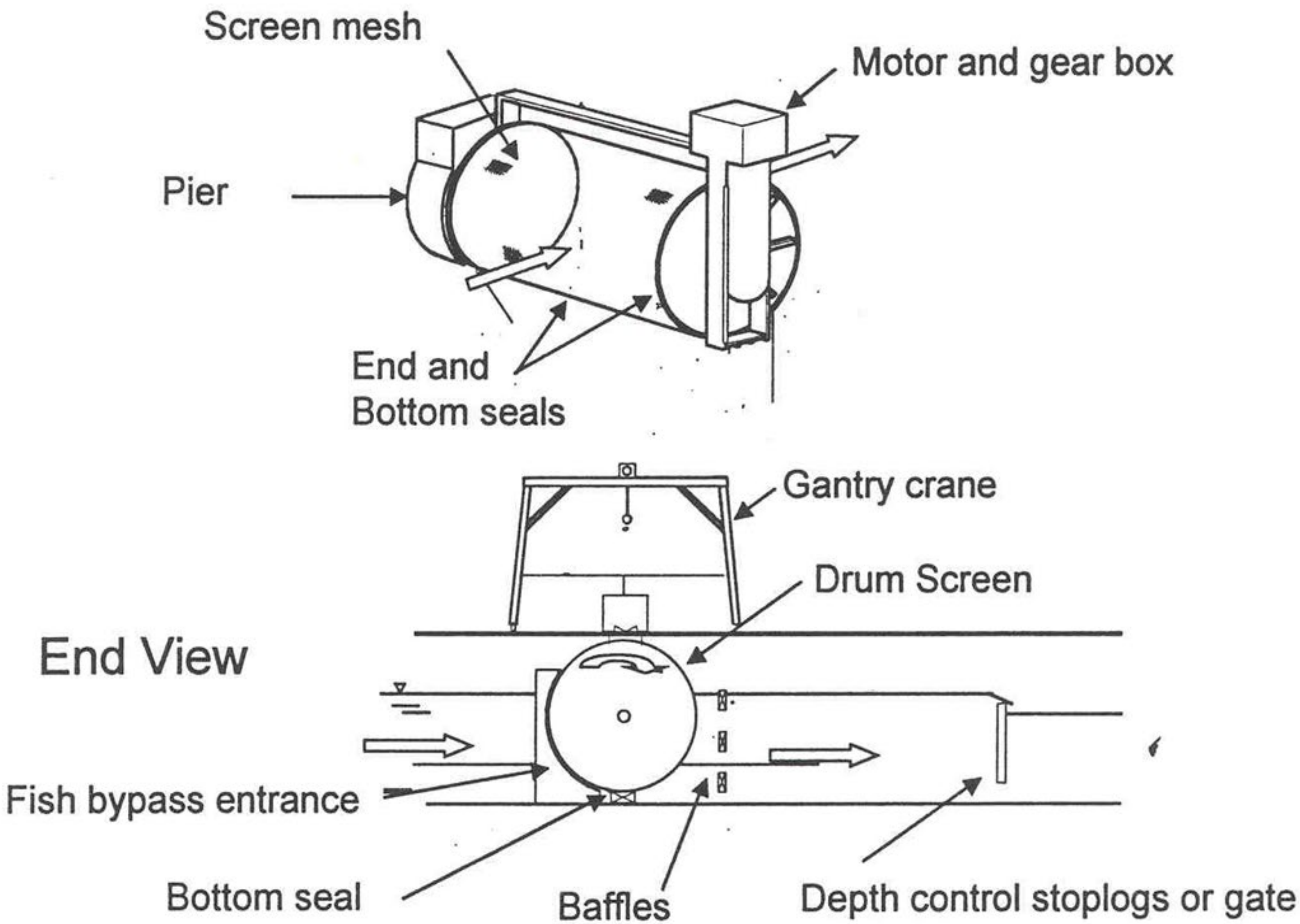

Cu-Ni
Stainless
Steel
11. 4. 2003

Screen Type Selection

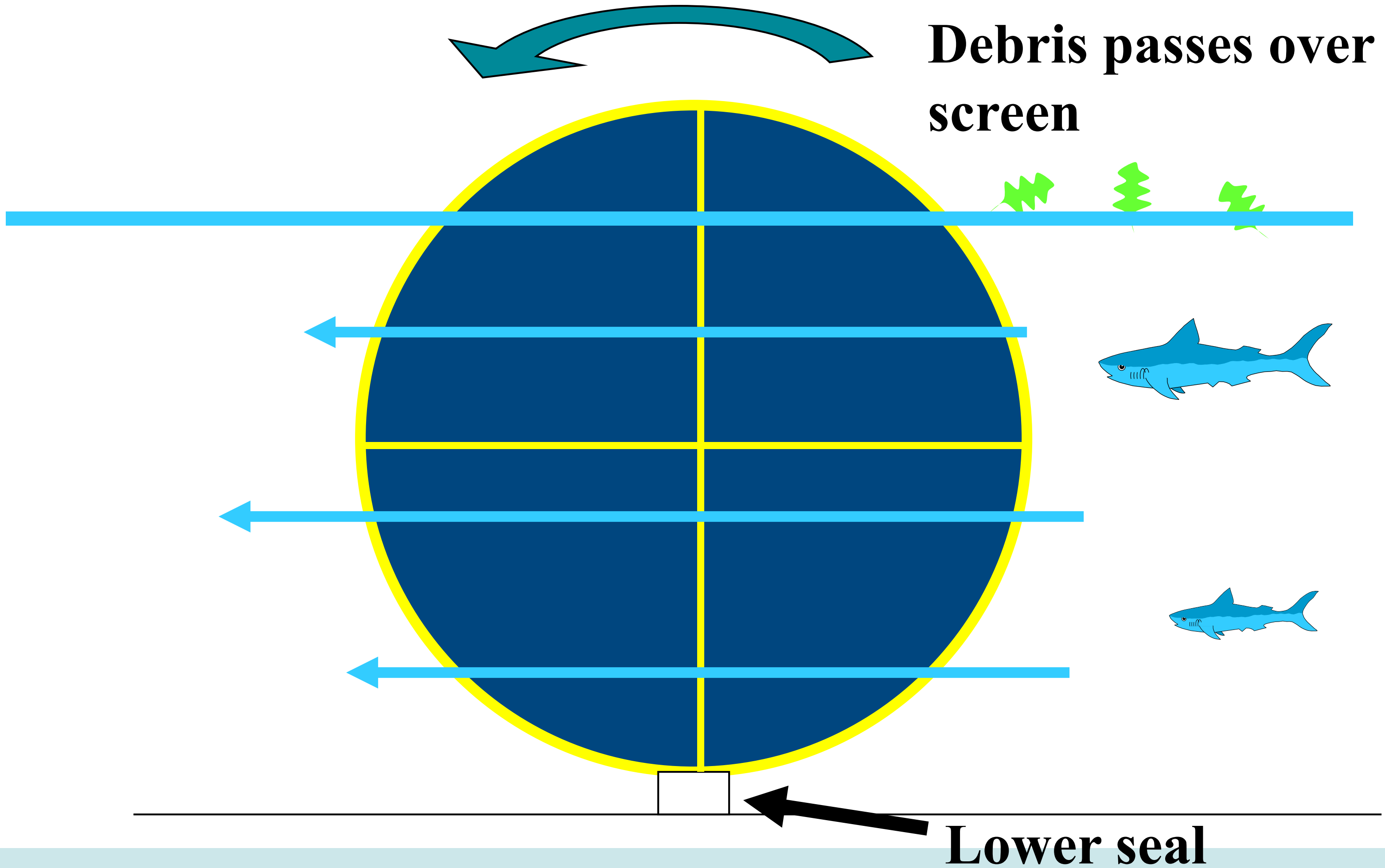
- Rotating Drum Screen (conventional style)
- Tee-Screen (fixed or rotating)
- Fixed Vertical Plate
- Vertical Travelling Screen (Belt of Panel)
- Non Vertical Fixed Plate
- Horizontal Fixed Plate
- Cone Screen
- End-of-Pipe Screen (pump screen)

Rotating Drum Screens

Rotating Drum Screen

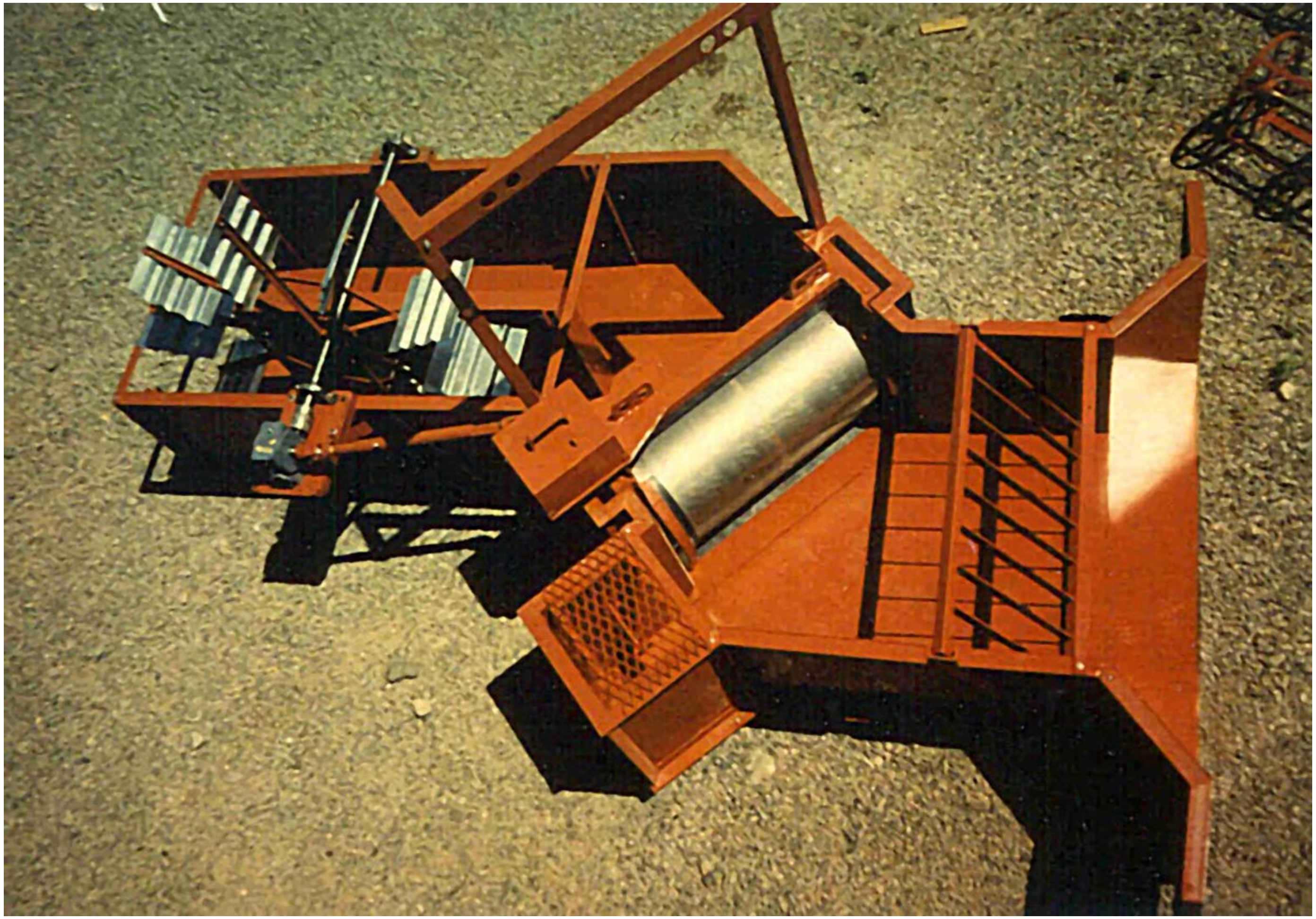


Drum Screen Operation

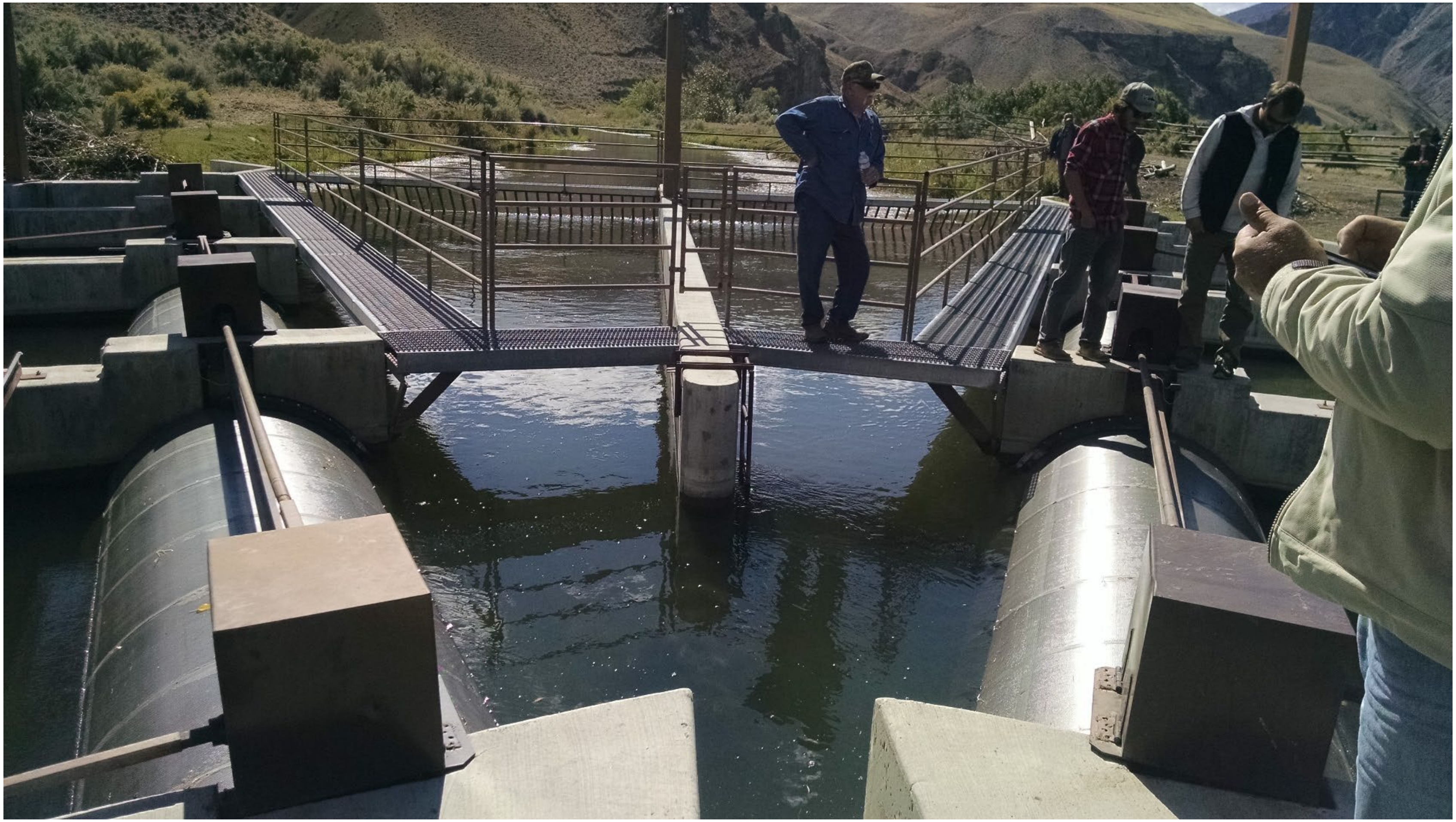


Rotating Drum Screen

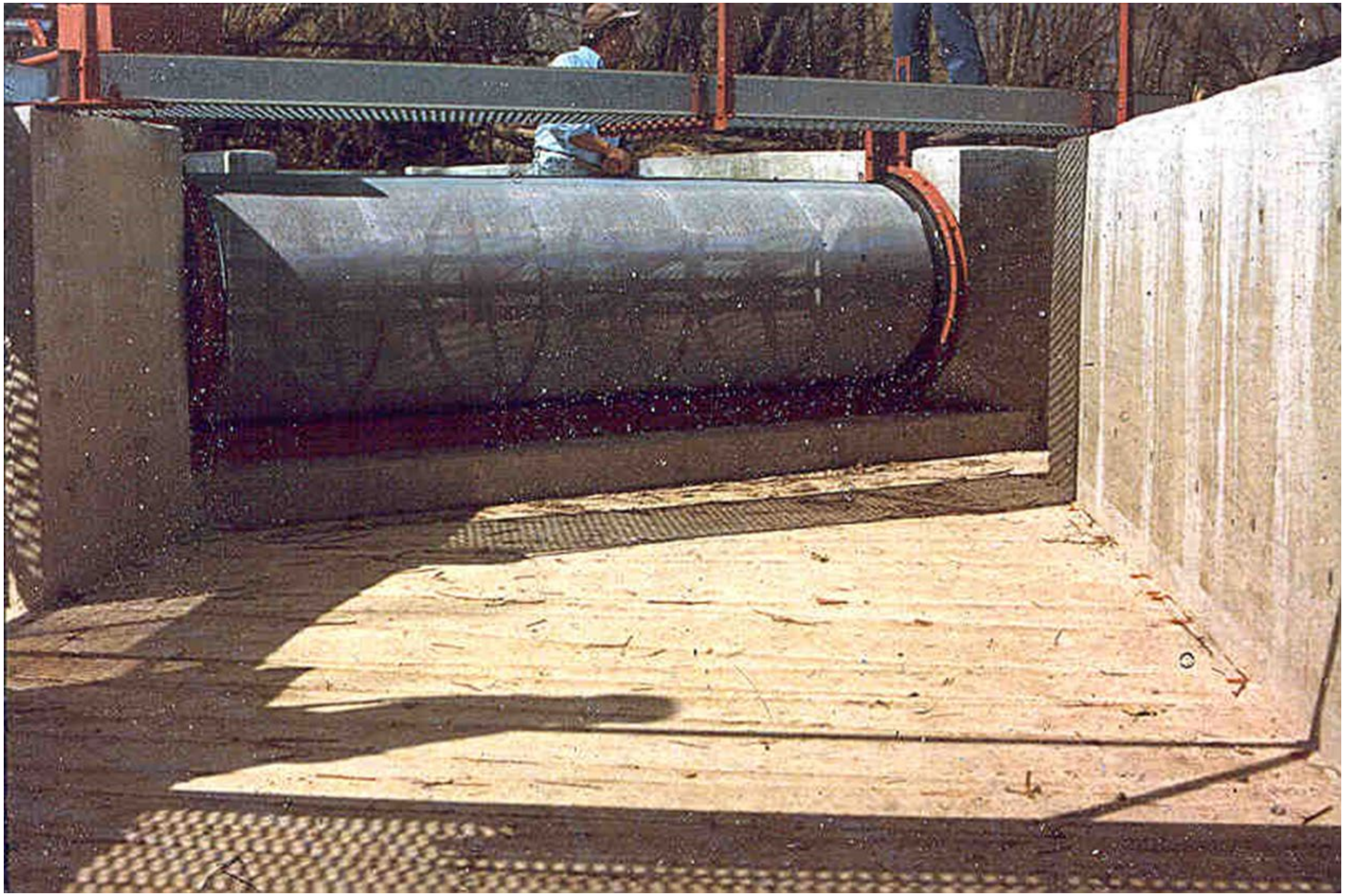
Rotating Drum Screen



Rotating Drum Screen-Vee configuration



Rotating Drum Screen-Seals



Rotating Drum Screen-Seals

Rotating Drum Screen-Advantages

- Proven fish protection
- Self-cleaning by rotation
- Passes debris downstream
- Easily used in un-powered areas (paddle wheel drive, solar)

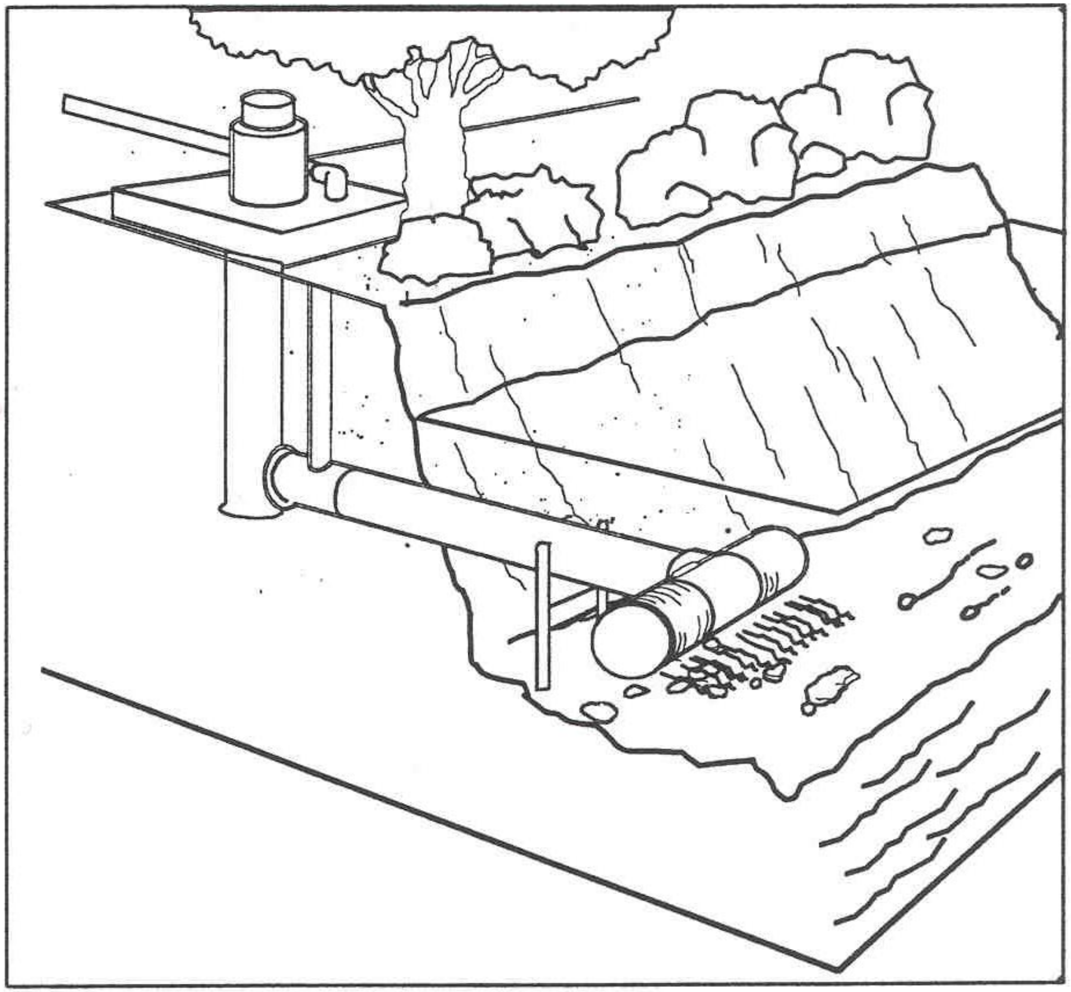
Rotating Drum Screen-Disadvantages

- Susceptible to direct hits from large debris
- Larger civil works are required.
- Seals require much maintenance.
- Susceptible to abrasions by sand - mesh requires periodic replacement.
- Passing debris downstream may require debris screens if using sprinklers
- Requires careful attention to water depth
  - 65% to 85% submergence
  - May require checkboards downstream

Tee Screens

Tee Screens

Tee Screens



Tee Screens - Advantages

- Good option for deep intakes
- Air burst cleaning system can be made to be effective
- Some have effective brush cleaners
- Some off-the-shelf models with water backwash systems meet NMFS criteria for active screens.
- Some can be easily removed for off-season

Tee Screens - Disadvantages

- Out of sight, out of mind
- Need current to transport debris from screen site.
- Air burst systems on large installations don't always clean entire screen - especially the bottom.
- Long, stringy vegetation is a problem on small pump screens.
- Requires sufficient depth to meet clearance criteria
    - ½ Screen diameter all around screen
    - Therefore min water depth must be 2x screen diameter

Vertical Fixed-Plate Screens

Vertical Fixed-Plate Screens

Vertical Fixed-Plate Screens

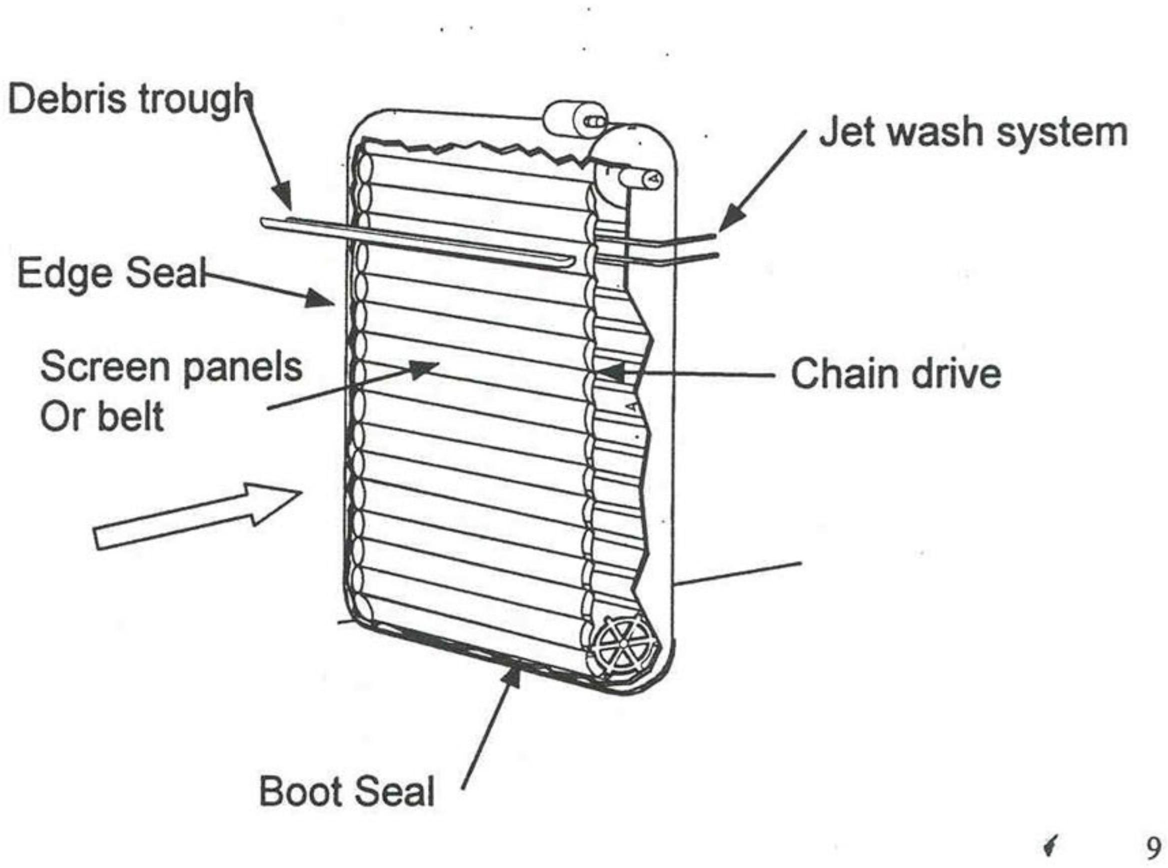
Vertical Fixed Plate Screens - Advantages

- Easy to seal
- Easily configured in Vee for more screen area in limited footprint
- Mechanically simple (relatively)
- Can be installed on river's edge
- No bypass required (if installed in-channel)
- Can use profile wire (very strong)
- Mechanical/brush cleaning usually effective
- Air burst cleaning system may be alternative

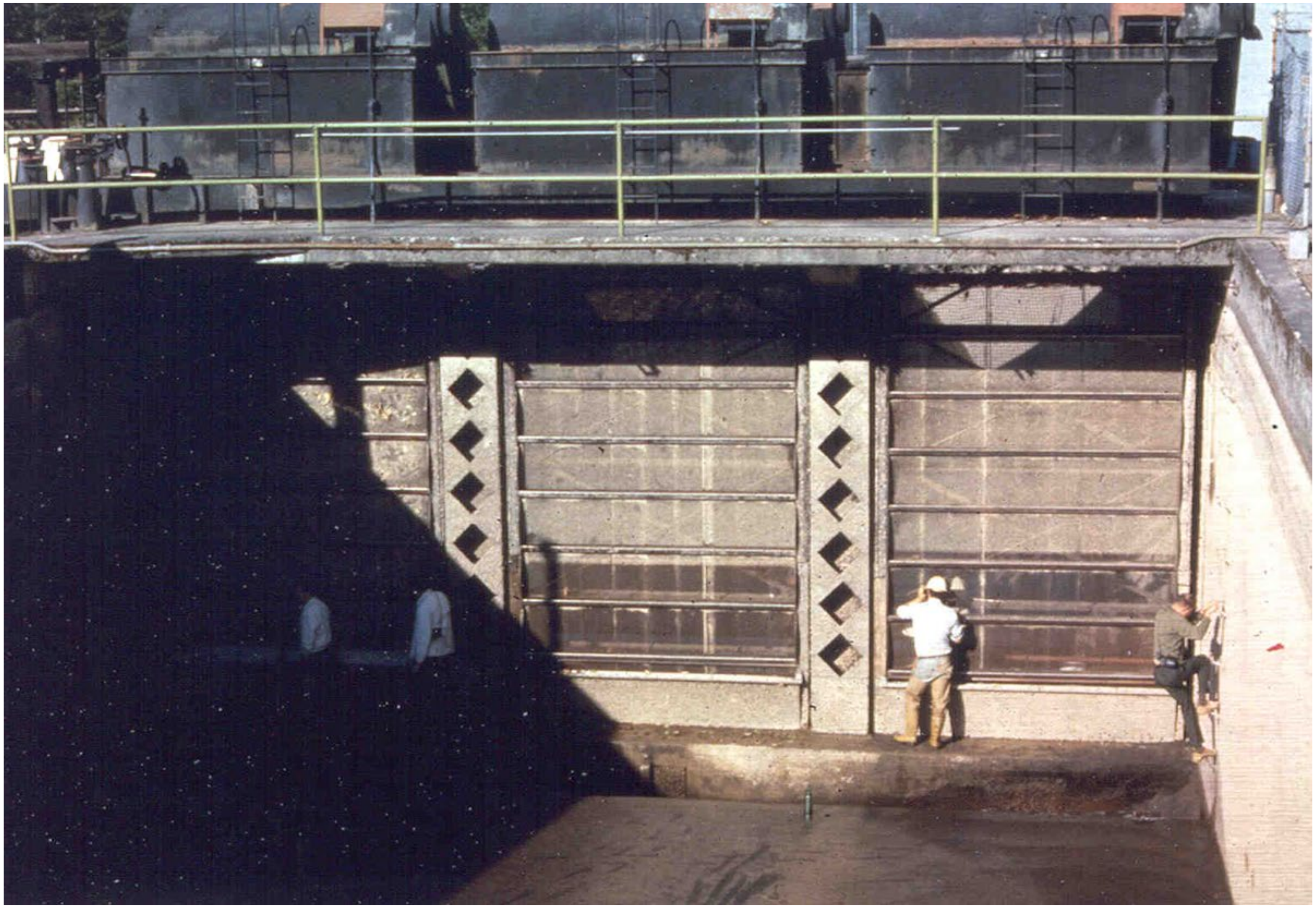
Vertical Fixed Plate Screens-Disadvantages

- Large bypass flows often required if installed in canal
- Brush arms can be damaged by large debris
- Sediment accumulation can cause brush problems
- Very tall screens can have difficulty holding brush tight to screen
- Brush cleaners can be mechanically complex

Vertical Travelling Screens



Vertical Traveling Screens



Vertical Traveling Screens

Vertical Traveling Screens

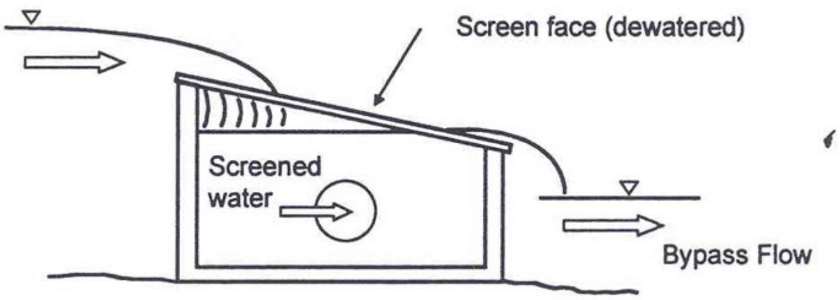
Vertical Traveling Screens - Advantages

- Small screens can be installed on river.
- Compact civil works
- Self cleaned by rotation (similar to rotary drum screens)
- Jet sprays provide additional cleaning.
- Possible to add trash conveyor behind screen to keep debris out of canal

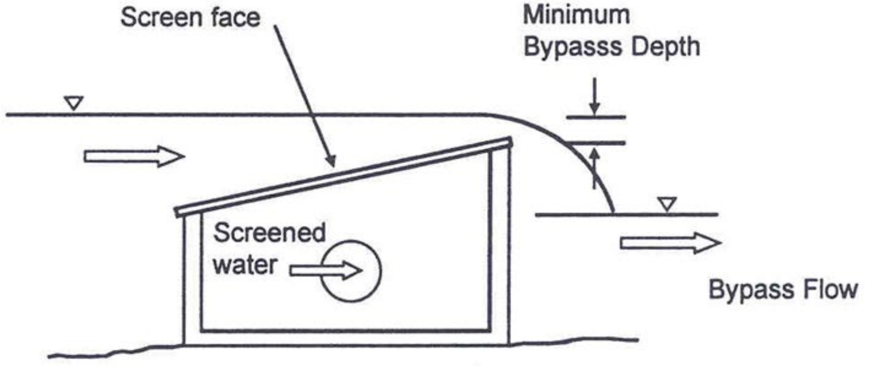
Vertical Traveling Screens - Disadvantages

- Mechanically complex.
- Seals can be a problem.
- Bedload sediment can be a problem.
- In some cases, stretching has been an issue.
- When installed vertically, may not adequately remove debris.

Non-Vertical Fixed Plate Screens



Downward Sloping Flat Plate Screen



Upward Sloping Flat Plate Screen

Non-Vertical Fixed Plate Screens

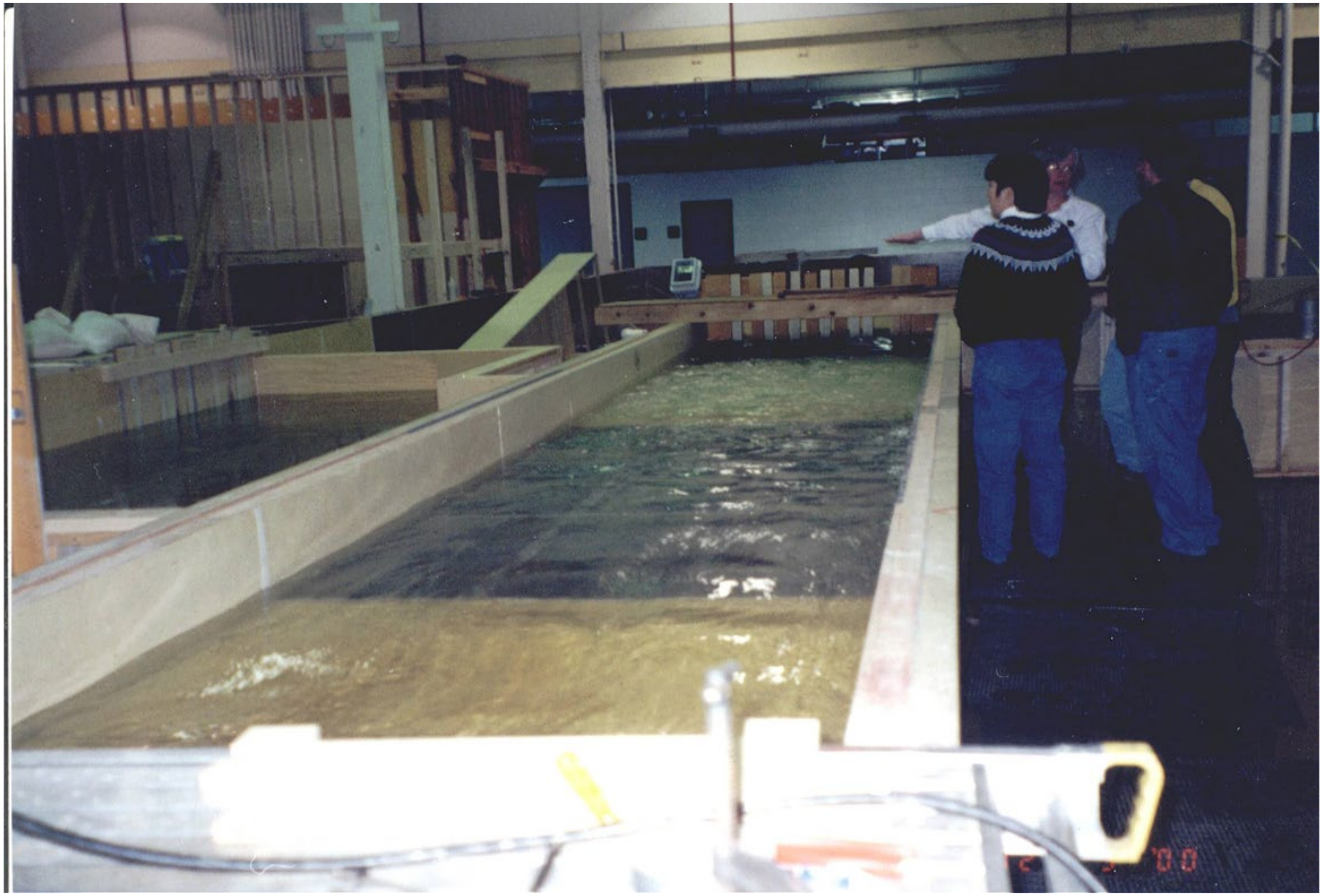
Non-Vertical Fixed Plate Screens - Advantages

- No moving parts
- No bypass required if built in-river*

Non-Vertical Fixed Plate Screens-Disadvantages

- Self-cleaning may not be reliable
- Risk of injury on screen during low flow
- Must raise water surface
- Tricky, unreliable flow rate control
- Adult concerns
- Under current criteria, must be able to maintain 1-foot depth over screen at all points.
- Often requires large bypass flow ratio for smaller screens

Horizontal Screens



Horizontal Screens

Horizontal Screens

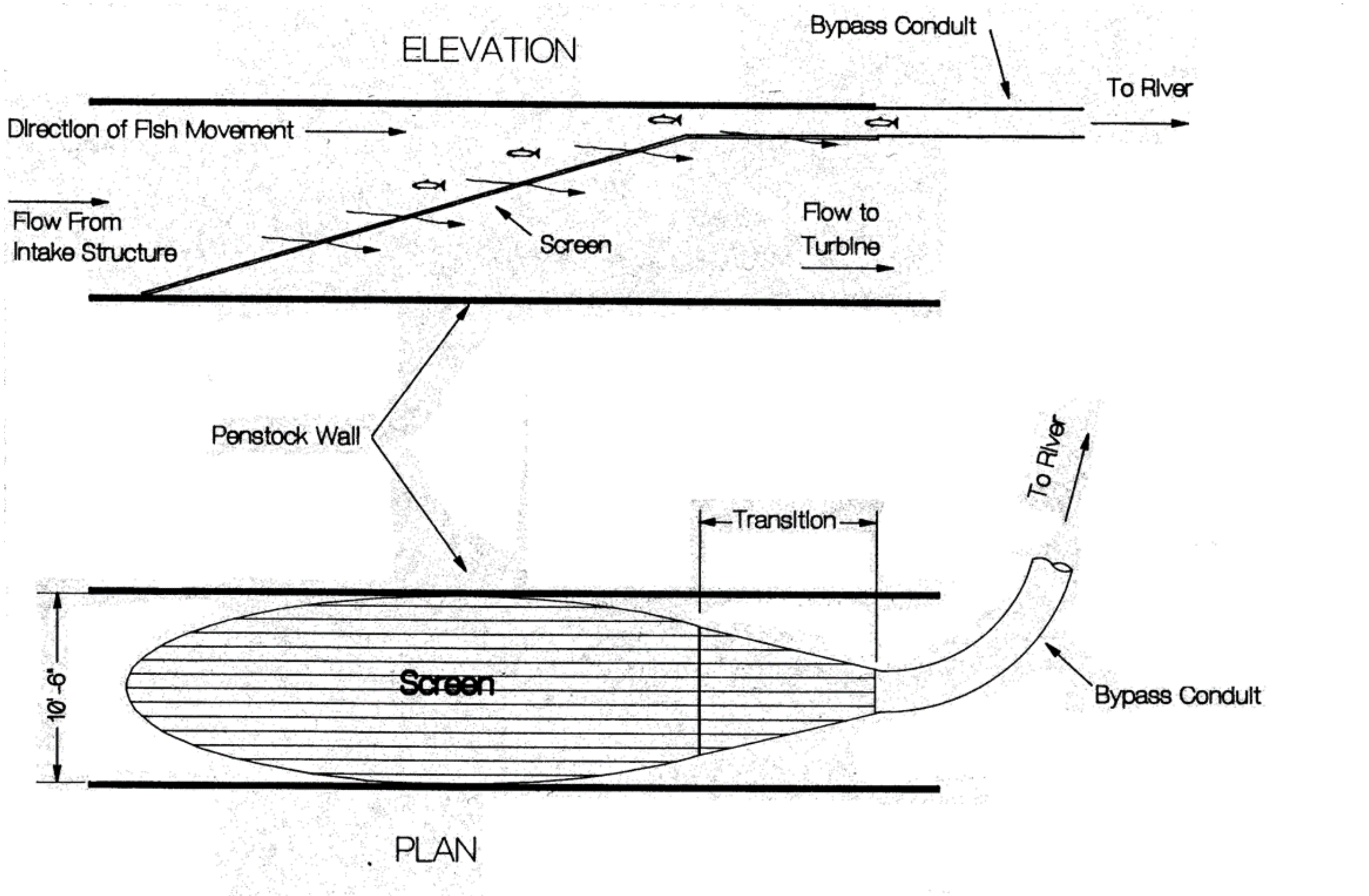
- Advantages and disadvantages similar to generic non-vertical fixed plate.
- Horizontal Screen Specific Criteria:
    - Straight entrance channel for at least 20-feet upstream of screen leading edge
    - Bypass flow depth minimum 1-foot
    - Must be equipped with automatic shutoff if inadequate bypass flow occurs
    - Must have means for sediment removal from under screen
    - Approach velocity <0.25 fps (typically much lower)
    - Works best if sweep to approach ratio 20:1 or better

Cone Screens

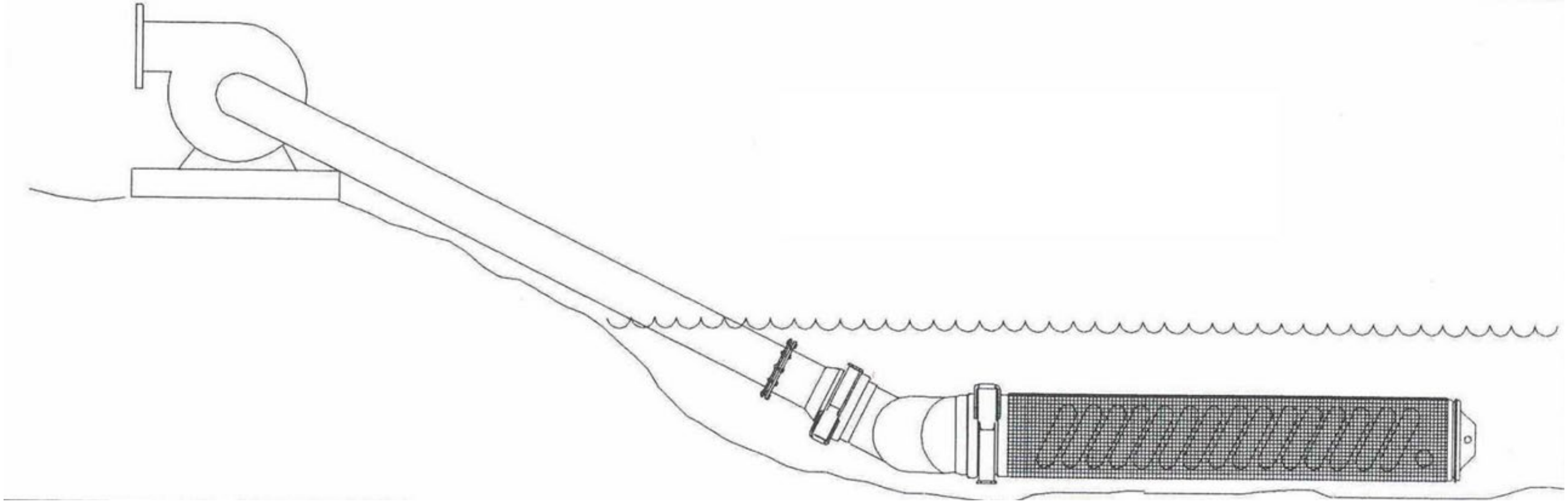
Cone Screens

- Self contained system similar to retrievable tee-screens.
- Often effective in shallow water.
- May require internal baffling in high velocity rivers.
- Often placed directly in river.

Eicher and Modular Inclined Screens



End of Pipe Screens/Pump Screens



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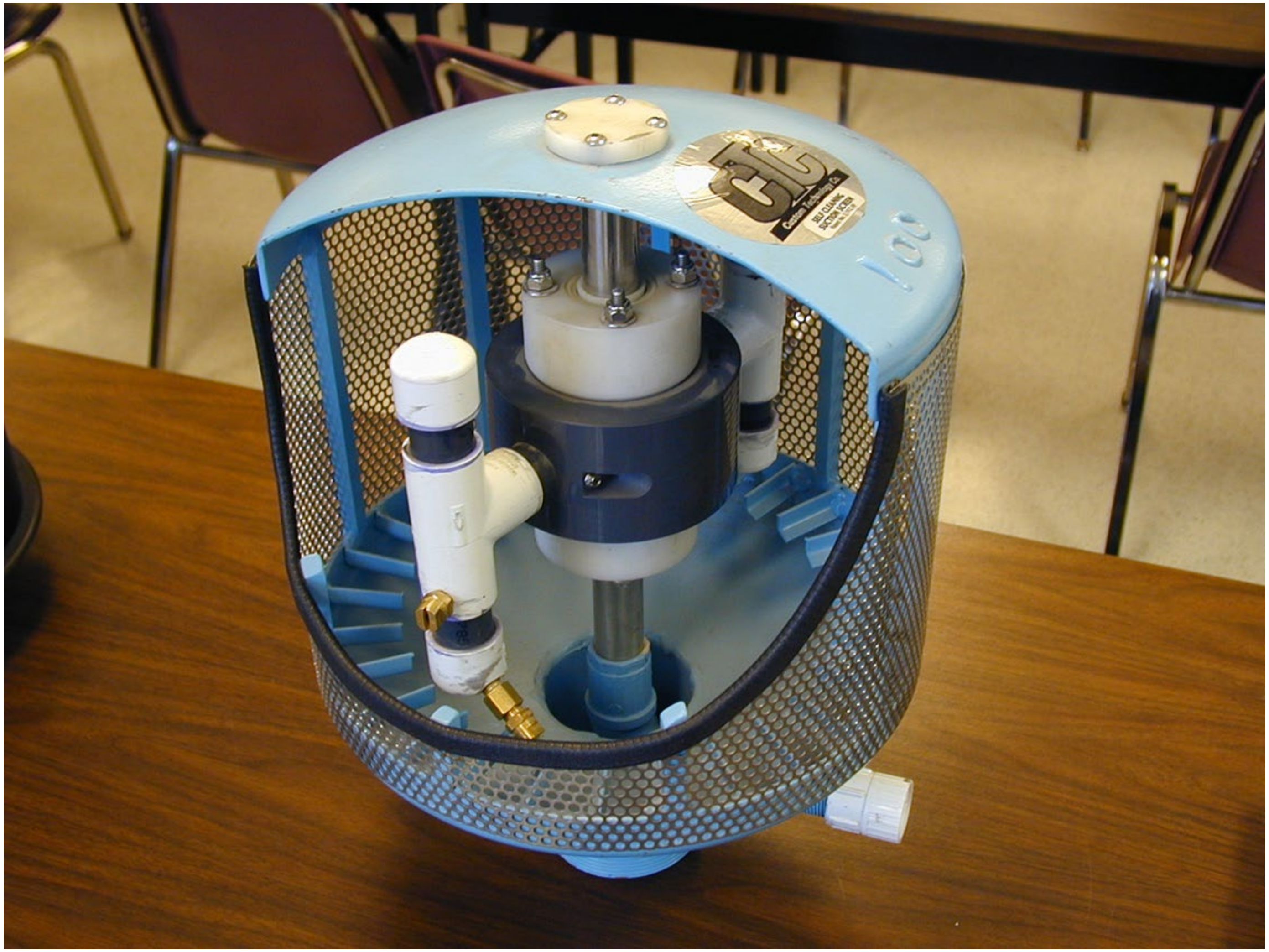
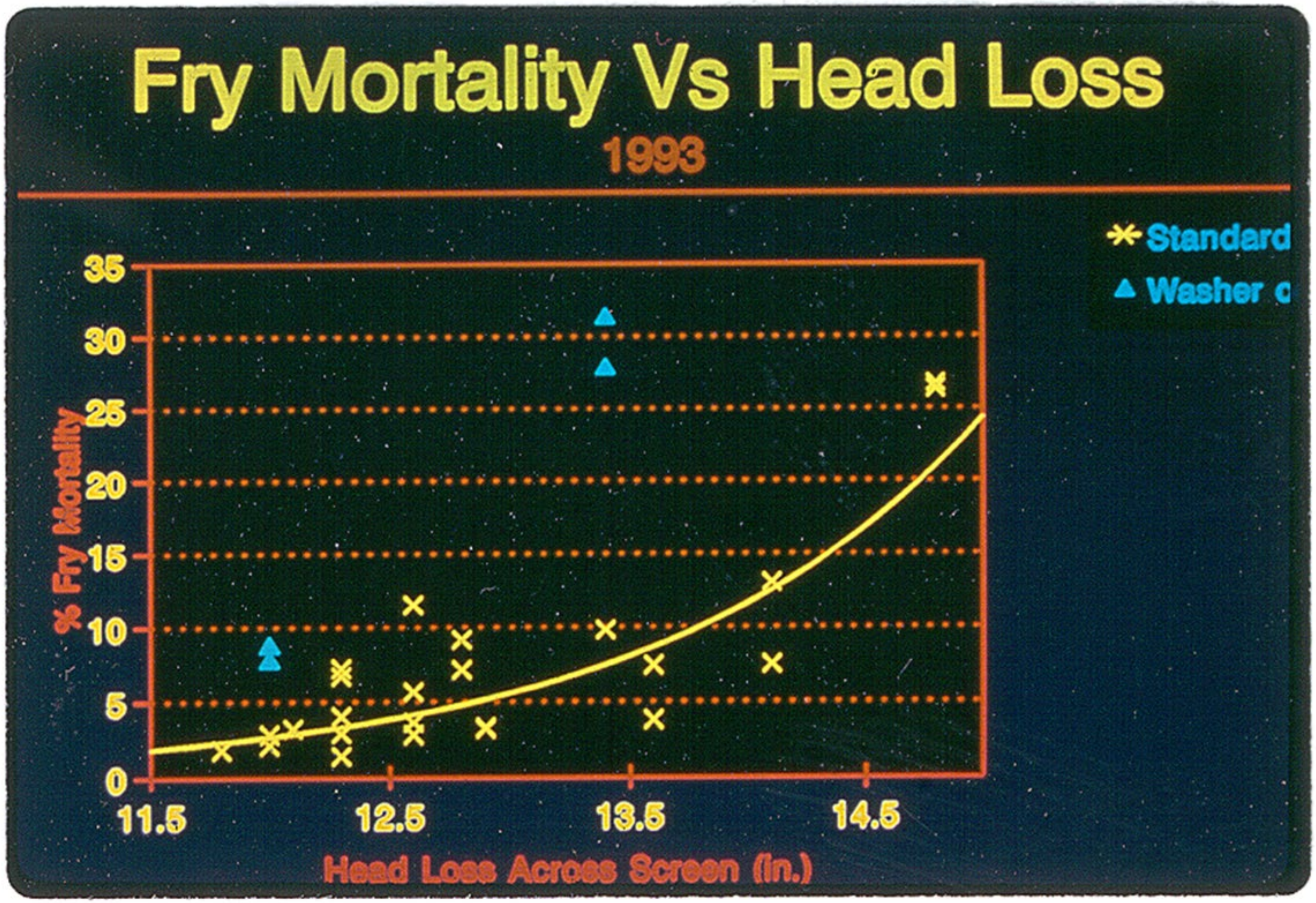


End of Pipe Screens/Pump Screens

Screen Cleaning System

- Screens shall have automatic cleaning system
- Effective, reliable, proven, approved by NMFS
- Cleaning initiated on timed intervals <u>and</u> on head loss
- Head differential to initiate cleaning = 0.1 ft **<u>over clean screen condition</u>**
- Cleaners should operate from upstream to downstream
- Sweeping velocity or other debris removal mechanism must be present
- Select most appropriate cleaner based on…

Screen Cleaning Systems



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Passive Screens

Passive Screens only allowed:

- Debris load generally low
- Flow less than 3 CFS
    - Screens may be manifolded together, but not to get around 3 CFS limit
- Sited in area of consistent river current to carry debris downstream
- Approach velocity less than 0.2 FPS
- Approved maintenance plan provided.

Screen Cleaning System

Screen Cleaning System

Screen Cleaning System - Brush Cleaners

- Brush Cleaners
- Travelling brush moves across screen surface on mechanical tracks.
- Ordinarily electrically operated.
- Occasionally hydraulic or paddle wheel operated
    - Reversing action can be difficult
- Screen mesh should be oriented in direction of brush travel. (profile bar)
    - This point is debatable. Some types of debris clean better when brush crosses mesh perpendicularly.
- Operated on timer as well as head differential trigger.
- Cleaning brush should “step off” of screen for return to upstream end in order to release debris.

Screen Cleaning System

Screen Cleaning System - Air Backwash

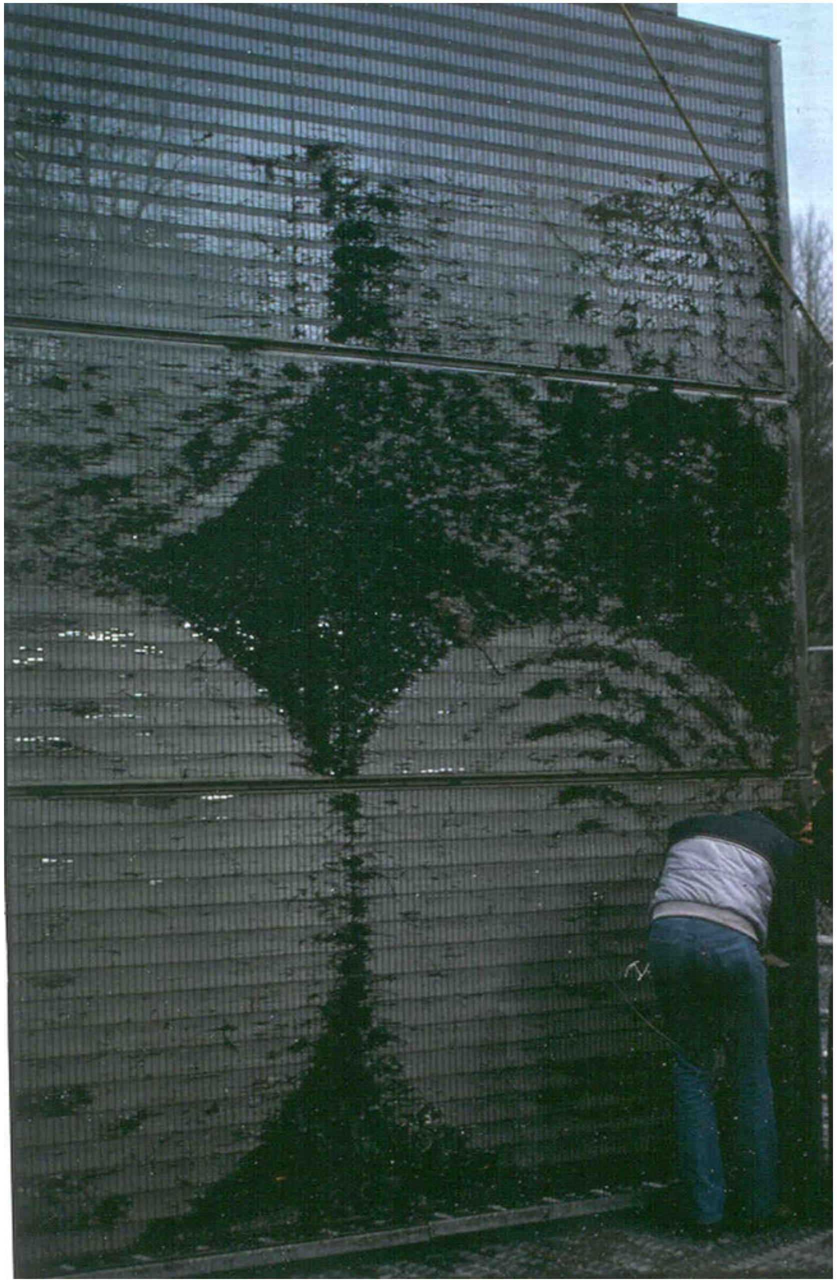
- Airburst Cleaning Systems
- Use compressed air to blow debris off of screen surface.
- Operated on timer as well as head differential trigger.
- Air burst should be designed to clean all surfaces of screen
- Effective area (for sizing purposes) of screen only includes cleaned area.
- Often used on end of pipe cylindrical screens.
- Important that removed debris be swept away.
- Should clean upstream to down.
- Some vegetation will grow extensively given air backwash. If this is present in river system, airburst cleaners should not be used.

Air burst cleaning systems may stimulate algae growth.

Air burst cleaning systems lift debris, sweeping flow moves debris downstream.

Screen Cleaning System

Screen Cleaning System



Screen Cleaning System - Water Backwash

- Water Jet Cleaning Systems
- Use pumped water to blow debris off of screen surface.
    - This can be convenient for pumped diversions.
- Operated on timer as well as head differential trigger.
- Effective area (for sizing purposes) of screen only includes cleaned area.
- Sometimes used on end of pipe cylindrical screens.
- Important that removed debris be swept away.
- Should clean upstream to down.

Screen Cleaning System

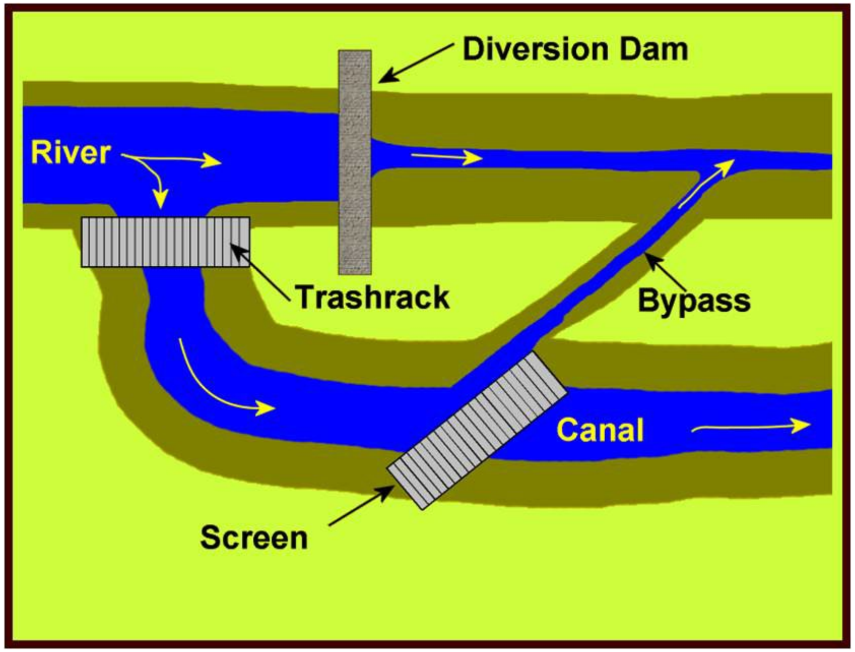
Screen Cleaning System

Screen Cleaning System

Screen Cleaning System

Screen Bypass Design

- Bypass route must be provided to move fish from the diversion back to the stream
- If off stream screen is used, a formal bypass is required.

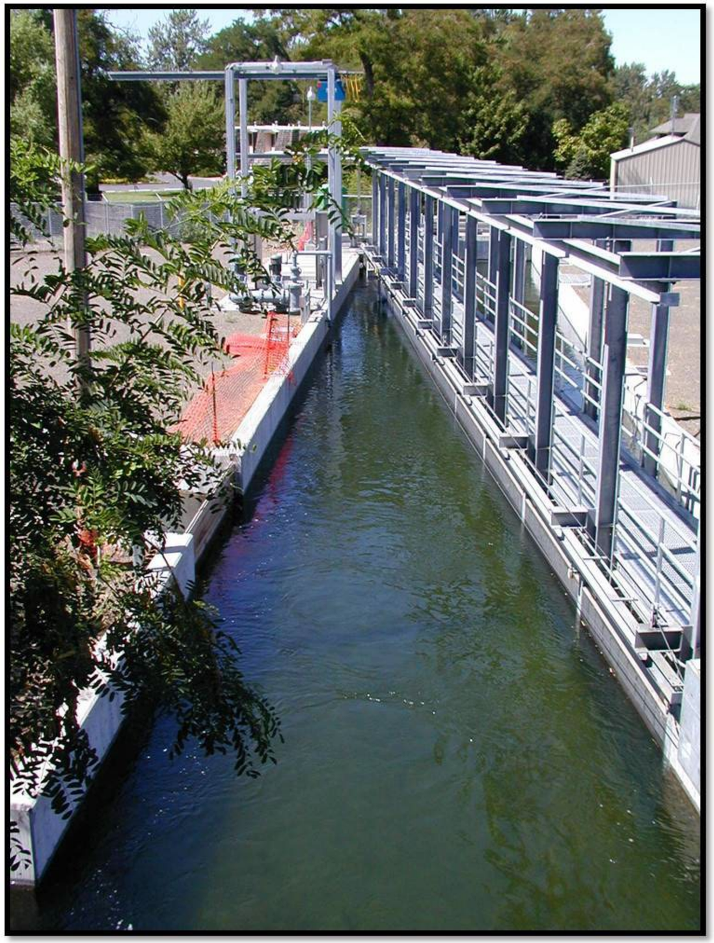


Bypass Design – Layout

- Location
  - Entrance must be located so it is easily found by downstream migrants.
  - Screens greater than 6 feet in length must be constructed with downstream end terminating at bypass entrance.
  - Screens less than 6 feet in length may be constructed perpendicular to flow with bypass entrance at either or both ends of screen.
  - For high flow diversions with long screens, it may be required to have intermediate bypass entrances.
    - The criterion for this is a 60 second screen exposure
    - If the sweeping velocity is not sufficient to carry the fish across the full length of the screen into the bypass in sixty seconds, an intermediate entrance is required.

Bypass Design – Layout

- Training Wall
  - In order to maintain sweeping velocity across screen face, a training wall must be located at an angle to the screen face, with the apex of the angle containing the entrance to the bypass.
  - In many cases, the wall of the civil works opposite the screen acts as a training wall.
  - Due to their nature, Vee-screens may not require a training wall.



Bypass Design – Layout

- Dewatering
  - Water diversion is not necessarily a year round affair, and to protect screens from high flows, or to perform maintenance, the screen and bypass may be dewatered at times.
  - The screen floor should be designed such that when flow diversion ceases, all water drains through the bypass, returning fish to the stream.
  - If this is not possible, a NMFS approved salvage plan must be developed.

Bypass Design – Entrance

- Entrance
  - The bypass entrance can be one of the most critical design aspects of the screen design.
  - Several elements to proper entrance design.

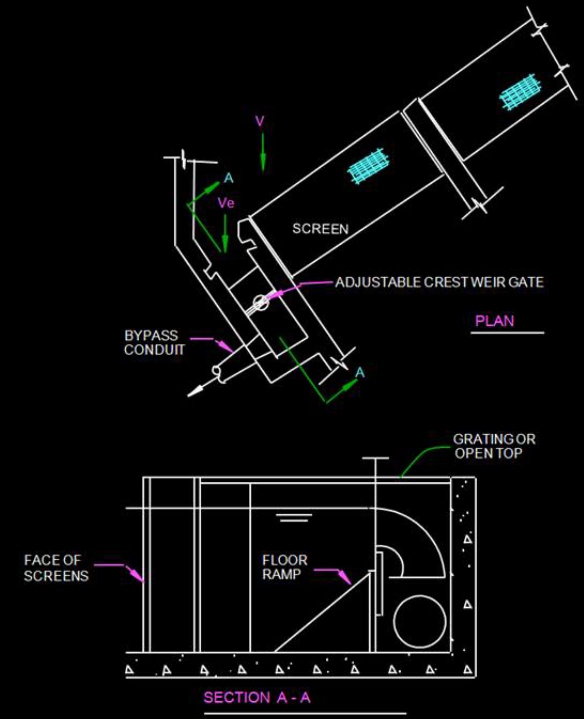


FIGURE 15 - BYPASS ENTRANCE

Bypass Design – Entrance

- Velocity
  - Minimum bypass entrance flow is 110% of maximum canal velocity upstream of entrance.
  - Bypass velocity gradients should be gradual and should never decrease at any point in the bypass.
  - Ensure bypass flows are sufficient to meet these conditions at all combinations of streamflow and diverted flow during the smolt out-migration period.

Bypass Design – Entrance

- Lighting
  - Ambient lighting must be included upstream of the bypass entrance.
  - Lighting transitions should be avoided when possible and gradual when required
  - More rapid lighting transitions may be permitted in areas where velocity exceeds capture velocity of migrants.

Bypass Design – Entrance

- Dimensions
  - For diversions greater than 3 cfs, full height entrances are required (floor of canal to water surface) with minimum width of 18 inches.
  - For smaller diversions, minimum width is 12 inches.
  - Size entrance to accommodate full range of bypass flow.

Bypass Design – Entrance

- Entrance Flow Control
  - Weirs are sometimes used to control quantity of bypass flow using adjustable weir crest elevation.
  - These weirs are located a short distance downstream of the bypass entrance.
  - For diversions greater than 25 cfs, depth over weir must be at least 1 foot.

Bypass Design – Entrance

- Entrance Flow Control, Cont.
  - Flow should accelerate no faster than 0.2 fps per foot length in the bypass entrance.
  - Weirs should have sufficient hydraulic drop to prevent fish from moving back upstream
    - Must also have sufficient downwell volume to prevent excessive turbulence without excessive volume that might create a predator holding area.
  - Valves should not be used in the bypass line to control flow due to potential to injure fish.
  - Must also have sufficient downwell volume to prevent excessive turbulence without excessive volume that might create a predator holding area.
  - Size downwell volume around EDF of 8-10 ft-lb/s-ft3

Bypass Design – Entrance

- Entrance Flow Control, Cont.
  - Flow Reduction Orifices
    - In extremely low flow diversions, even though 10" pipe is required by criteria, flow can be reduced by installing orifice plate over pipe inlet.
    - Minimum opening 6"
    - Can't be used where adults may be moving upstream though bypass.
    - Shouldn't be used where steelhead kelts occur.
    - Debris management can be problematic.

Problem with "Mouse-Hole"

Bypass Design – Conduit

- Bypass Conduit
  - Conditions in bypass conduit should have smooth surfaces to minimize turbulence, catching debris and fish injury.
  - Bypass pipe length should be minimized when possible, but length is a secondary consideration to locating the bypass return as close as possible to point of diversion.
  - Due to concerns with open channel bypasses (predation, lack of hydraulic control, etc) closed pipe bypasses are preferred subject to certain limitations.
    - Pressure equal to or above atmospheric (no vacuum).
    - Avoid pressure transitions.
    - Trapped air allowed to escape.
    - Inspection access provided where debris anticipated and at regular intervals

Bypass Design – Conduit

- Bends
  - Bends in bypass conduit should be avoided if possible due to potential for debris accumulation.
  - Where required, bends must have minimum radius of curvature greater than or equal to 5 pipe diameters.
    - If bends are made with one or more mitered pipe joints, miters must be 11.25 or 15 degree angles and must be separated by a sufficient distance to allow entire assembly to meet minimum radius of curvature
  - More gradual bends may be required if high velocities are present in bypass.

Bypass Design – Conduit

- Sizing of bypass conduit is a function of flow and slope in order to achieve velocities and depths within criteria
- Sizing must also take into account expected size of debris that may enter bypass.

Diverted Flow (cfs)	Bypass Flow (cfs)	Bypass Pipe Diameter (in)	Bypass Flow Depth(in)
<6	5% of diverted flow	10	2.5
6-25	5% of diverted flow	10	4
40	2.00	12	4.75
75	3.75	15	6
125	6.25	18	7.25
175	8.75	21	8.5
250	12.5	24	9.5
500	25.0	30	12
750	37.5	36	14
>1000	Design with direct NMFS engineering involvement		

Bypass Design – Conduit

- Flow, Velocity, and Depth
  - Bypass flows should generally exceed 5% of total diversion flow.
  - Velocities should range from 6 to 12 feet per second, though higher velocities may be approved
    - If using higher velocities, special attention should be paid to bends and joint smoothness.
  - Velocities less than 2 feet per second may allow for sediment accumulation and should not be used.
  - Design minimum depth in bypass conduit should be no less than 40% of conduit diameter. Greater than .75 feet is preferred.

Bypass Design – Outfall

- Outfall Impact Velocity:
  - To minimize fish injury due to shear forces, impact velocity (velocity at which bypass stream intersects with mainstem stream) must be less than 25 feet per second.
- Outfall Depth:
  - Depth of recieving water at outfall must be sufficient to prevent bypass flow (and entrained fish) from striking the bottom of the stream.

Bypass Design – Outfall

Bypass Design – Outfall

Bypass Design – Outfall

- Predation
  - Bypass outfall provides concentrated food source for predators.
  - Predation by birds and predator fish are of concern.
  - Even in the case of a well designed bypass conduit, fish can be disoriented or stressed.
  - Outfall design should allow for time for fish to recover and disperse.
  - Outfall should be into stream with velocity at least 4 fps to deter holding of predators.
  - Avoid creating “shadows” where predators can hold.

Bypass Design – Outfall

- Discharge and False Attraction
  - Bypass outfalls frequently a source of false attraction to upstream adult migrants.
  - Care should be taken to design outfall so upstream migrants jumping at outfall are not injured.
  - If adult fish can get into bypass, it may be necessary to provide upstream passage through the bypass to the upstream end of the diversion.

Operations and Maintenance

- Corrosion Control and Wear Management
  - Construct screens from non-ferrous materials to prevent rust.
    - Aluminum, Stainless Steel, and Plastic
  - In some cases, coatings can be effective.
  - For travelling screens, seals and screen material wear, and must be checked and periodically replaced.
  - Corrosion protection should include isolation of materials with disimilar metals". (eg caulk, non-ferrous washers, others)

Special Conditions - Ice

Special Conditions - Ice

- Ice Management:
  - Most screen out of service during icing season
  - Some must operate year round
    - Hatchery water intakes
    - Stock water intakes
    - Municipal Intakes
  - For minor icing conditions, fully submerged screens deal reasonably well (tee-screens, cone screens, etc)
  - For severe ice (anchor or slush ice), no great solution exists
    - Tempering wells may help
    - Sheltering screen in heated buildings

Special Conditions – Sediment/Bedload

- Screens should be sited to minimize potential problems with sediment deposition:
- Avoid local deceleration where reduced energy causes sediment to fall out of suspension
- If overtopping of screen may occur, consider covering screen.
- Particularly for air backwash screens, consider adding sediment clearing nozzles at toe of screen.
- Consider holding bottom of screen above river bed to allow for proper operation under some sediment build-up.

Special Conditions – Sediment/Bedload

Special Conditions – Sediment/Bedload

Water Drafting

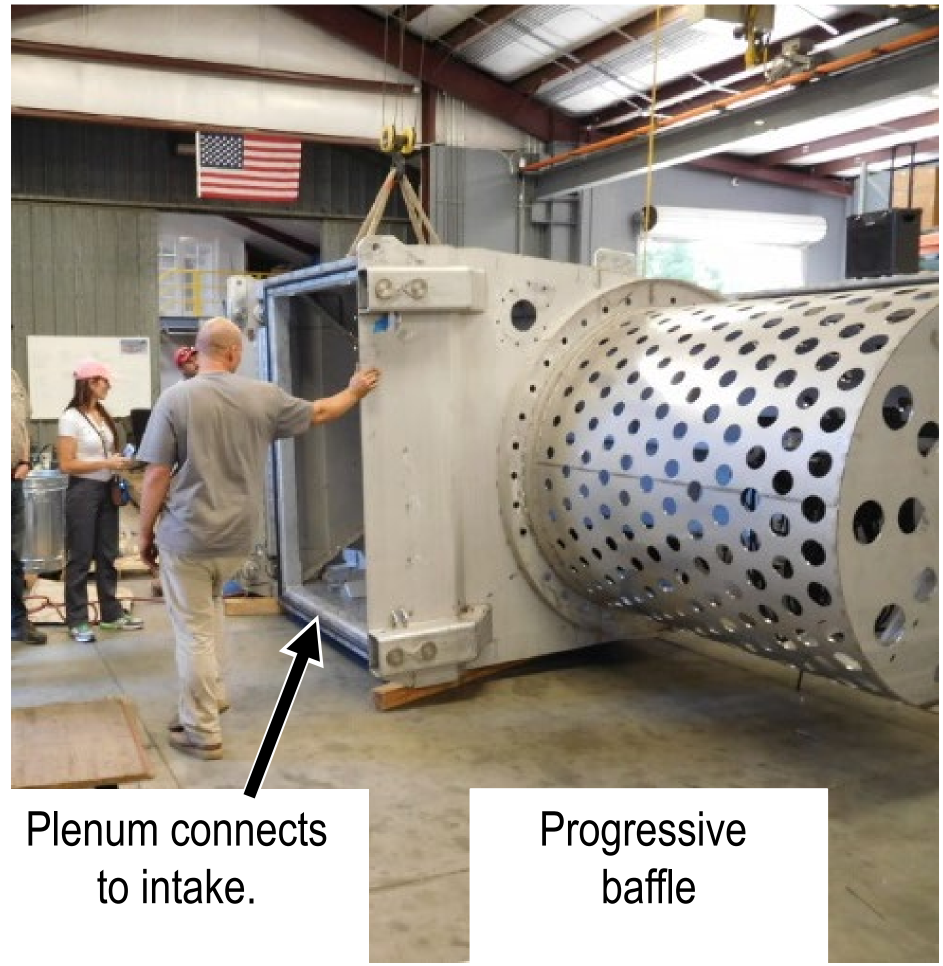
- Water withdrawal not tied to a specific water right
- Often used for firefighting and construction water supply
- All standard fish screening criteria apply*
  - Approach velocity max: 0.33 FPS
- Limited to 10% of current stream flow

Flow Distribution (Baffling)

- The screen design should provide for nearly uniform flow distribution over the screen surface, thereby minimizing approach velocity over the entire screen face.
- Baffles to distribute flow uniformly over all effective screen area may be fixed or adjustable.

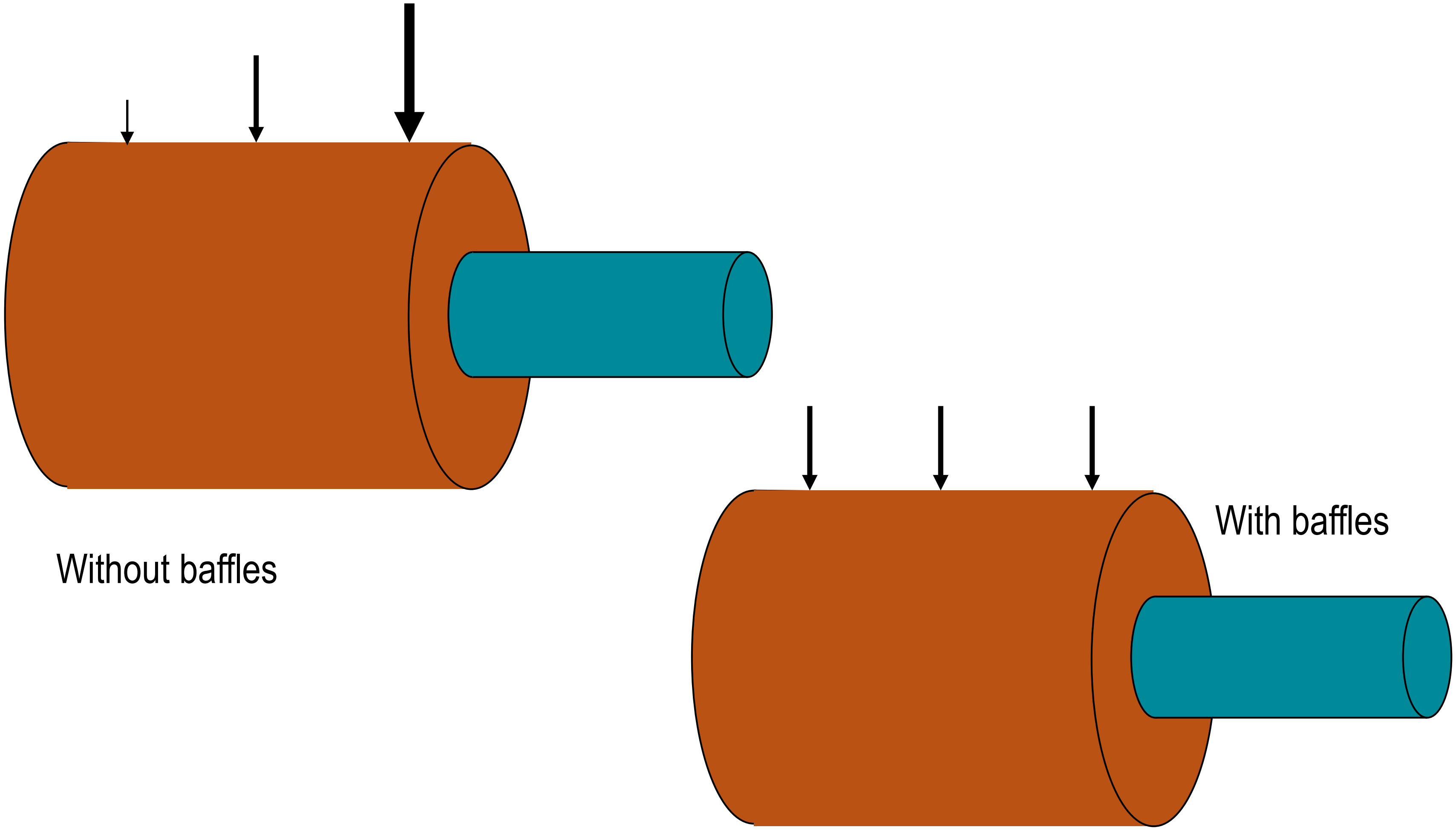
Baffle for Cylindrical Screen


Screen cylinder fits over baffles


Plenum connects to intake.

Progressive baffle

Flow Uniformity



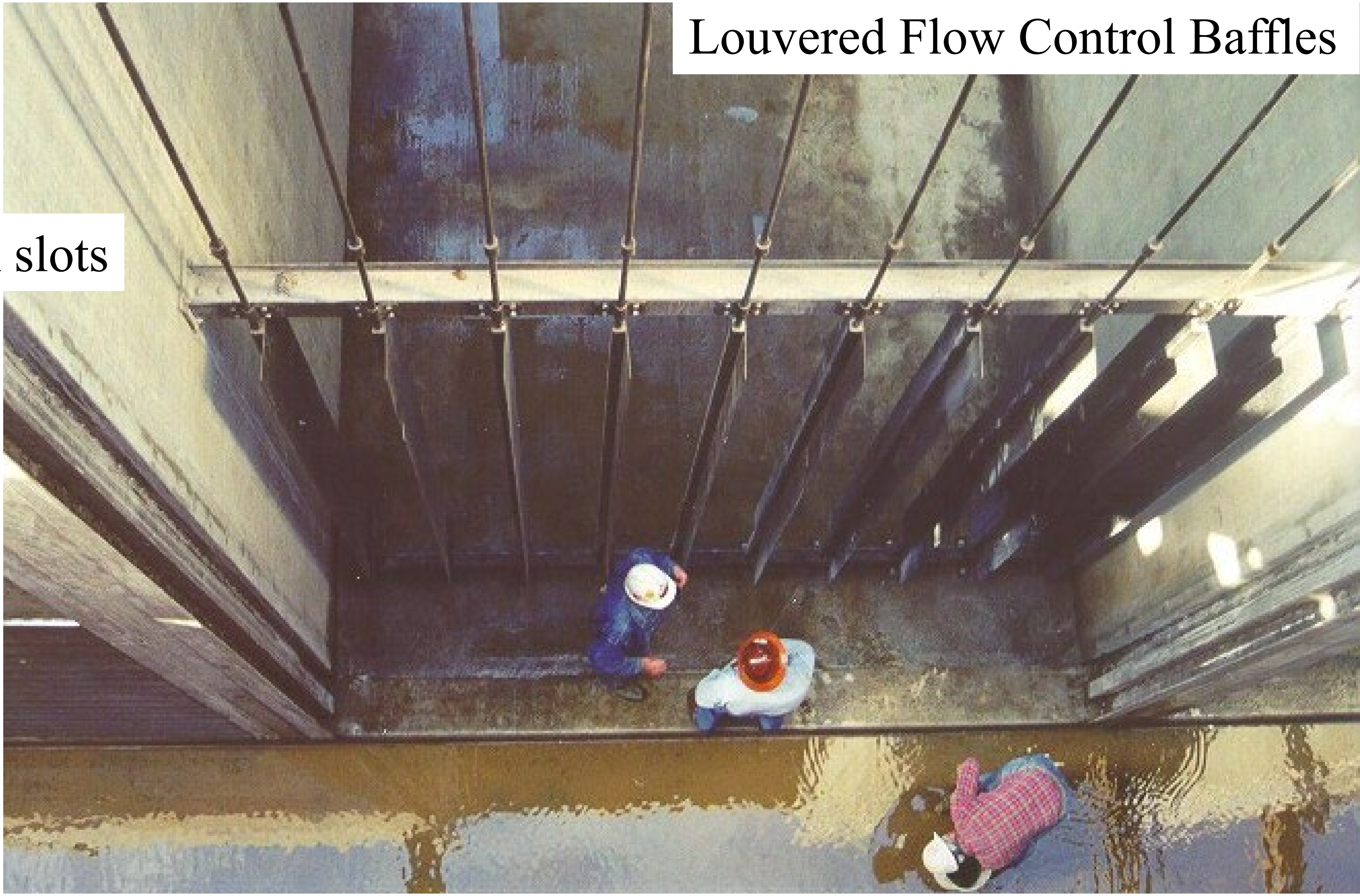
Porosity Plates Vs. Louvers

- Louvers
  - Vertical Slot along Each Edge of the Louver Blade
    - Flow Not Evenly Distributed over Screen Area
    - Small Adjustment can Have Large Impacts on Flow
    - Difficult to Fine Tune
    - Hydraulics Difficult to Pre-Design or Model Baffle Settings
    - Need to Field Set – Timely and Cost Consuming
- Porosity Plate Baffles
  - Small Baffle Holes Over Entire Area
    - Evenly Distributes Flow over Screen Area
    - Adjustments Have Smaller Impact on Flow – Easier to Fine Tune
    - Can Pre-Design Settings for Desired Flow Conditions
    - Required Field Adjustments are Minimal

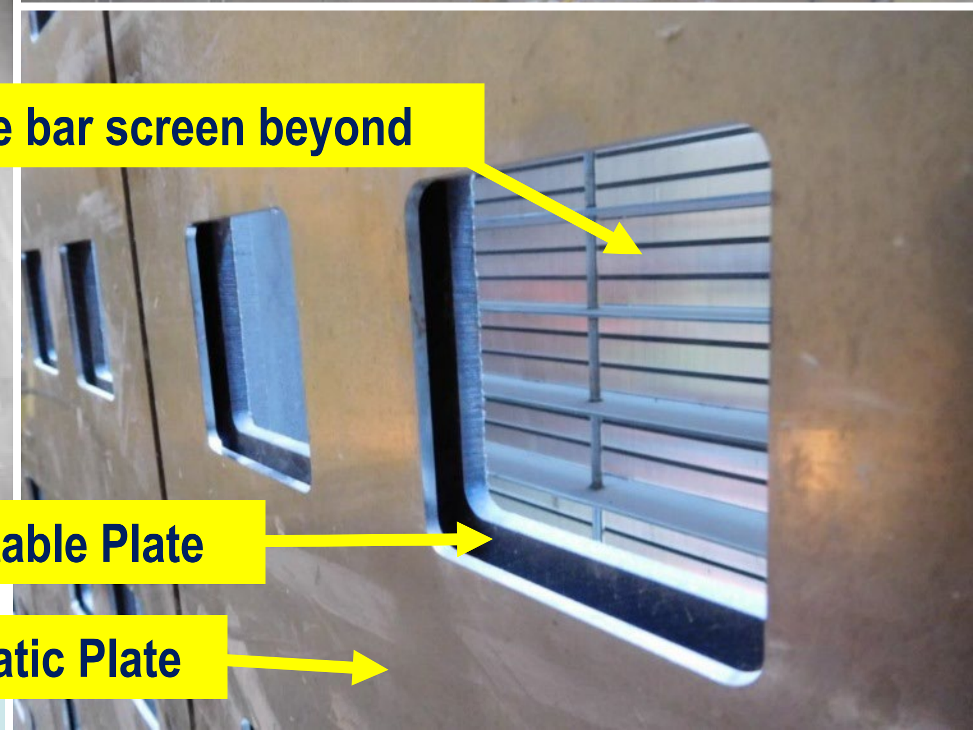
Baffles Used on Flat Plate Screens

Louver Style

Porosity Plate Style (Preferred)



RD 108 Wilkins Slough


Profile bar screen beyond
Adjustable Plate
Static Plate

Questions?