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DRAFT

# FISH PASSAGE AND PROTECTION CONSIDERATIONS FOR THE TONGUE RIVER, MONTANA, IN ASSOCIATION WITH THE TONGUE RIVER DAM REHABILITATION PROJECT AND FISH PASSAGE CONSIDERATIONS FOR CARTERSVILLE DIVERSION DAM, YELLOWSTONE RIVER, MONTANA

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Investigations by

Charles Liston, Perry Johnson, Brent Mefford, and David Robinson

United States Department of the Interior
Bureau of Reclamation
Technical Services Center
Denver, Colorado 80225

Submitted to

Bureau of Reclamation
Montana Area Office
PO Box 30137
Billings, Montana 59107

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## INTRODUCTION AND BACKGROUND

The Tongue River Basin in Montana has provided water and rangeland for organized agriculture since the 1870's. By 1900, ranching was the main economic activity of the area (U.S. Bureau of Reclamation, 1985). Completion of the Tongue River Project in 1940 made possible the stabilized production of hay, silage, and small grains through provision of relatively stable and predictable amounts of irrigation water in this semi-arid area. The Tongue River Project irrigates some 15,000 acres. The Tongue River Project is owned by the state of Montana and is administered by the Montana Department of Natural Resources and Conservation and the Tongue River Water Users Association.

Central to the Tongue River Project is the 91-foot-high Tongue River Dam, located approximately 189 river miles up from the confluence of the Tongue River with the Yellowstone River at Miles City, Montana (fig. 1). Water from snowmelt and runoff is stored and released gradually throughout the irrigation season. Presently, the Tongue River Project produces about 32,000 acre-feet of annual yield, considerably lower than the yield when the reservoir is at full storage capacity. Approximately 340,000 acre-feet of water flows through the reservoir annually (U.S. Fish and Wildlife Service (FWS), 1992). The lower yield is the result of an unsafe spillway and associated dam safety problems (in 1980, the U. S. Army Corps of Engineers classified the spillway as unsafe and "high hazard"). The unsafe conditions at the dam have led to the Tongue River Dam Rehabilitation Project, which will eventually replace the present spillway, improve the outlet works, and raise the reservoir's maximum water level 4 feet to provide additional storage for increasing water demands and claims. Construction may begin in 1996.

Other long-time features associated with historical agricultural water use from the Tongue River include several diversion dams which "pool" water along various river reaches, thereby providing "gravity-fed" water to nearby canals. The main diversion dams are shown on figure 1 as the T and Y Diversion Dam, 20 miles up from the confluence with the Yellowstone River; S and H Diversion Dam; Mobley's Dam; and Brewster's Dam. The dams have been in place for many decades and were constructed to serve the single purpose of providing gravity-fed water for agriculture. In common with hundreds of low-head diversion dams built on numerous rivers throughout the west, no concern was given to the needs of native fish species regarding in-river migratory behavior. Further, canal inlet works above the diversion dams were never screened to minimize fish losses to canal entrainment.

Fishery resource concerns associated with the Tongue River Dam Rehabilitation Project include both mitigation and enhancement features (FWS, 1992). Recommendations for mitigation concerning the Tongue River below the Tongue River Dam have included: 1) monitoring and possibly restocking smallmouth bass between the Tongue River Dam and Ashland, Montana; 2) supplemental stocking of smallmouth bass and channel catfish between Ashland and the T and Y Diversion Dam; and 3) development of a memorandum of agreement or other instrument for mitigating impacts of any presently unanticipated eventualities, i.e., an emergency or other shutdown of water releases at the Tongue River Dam during project construction that would threaten downstream fishery resources. Fishery enhancement recommendations for the Tongue River below the Tongue River Dam have centered on provision of adequate instream flows.

It has been suggested that a memorandum of agreement be developed by Montana Department of Natural Resources and Conservation, Montana Department of Fish, Wildlife, and Parks (MDFWP), and the Northern Cheyenne Tribe, including involvement with the Bureau of Reclamation (Reclamation) and FWS, which would address maximization of instream flows in accordance with MDFWP recommendations (FWS, 1992). The MDFWP has recommended that long-term seasonal flows be maintained below Tongue River Dam to maintain the resident fishery and to enhance spring sauger and shovelnose sturgeon spawning runs into the Tongue River from the Yellowstone River (Table 1). These recommendations were presented as minimum flows ($ft^3/s$) required monthly between T and Y Diversion Dam and the mouth of the Tongue River (Anderson and Bucher, 1990).

Table 1. Instream Flow Requirements for the Tongue River - T and Y Diversion to Mouth.

| Cubic Feet Per Second ($ft^3/s$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | Feb | Mar | Apr | May | Jun | Jul[1] | Aug | Sep | Oct | Nov | Dec |
| 190 | 190 | 190 | 525 | 600 | 600 | 600/ 225 | 225 | 190 | 190 | 190 | 190 |
| [1]July 1-15 = 600 ($ft^3/s$); July 15-31 = 225 ($ft^3/s$) | | | | | | | | | | | |

Anderson and Bucher (1990) analyzed the potential for the rehabilitated Tongue River Project to meet these flows, assuming that Wyoming would not use its water rights under the Yellowstone River Compact of 1950. The above flow recommendations could be met 80 percent of the time in April and May, while June flows could be met 60 percent of the time. July flows could rarely be met, and late summer flows would not be met for resident species. Winter flow recommendations would be met. Additional fishery enhancement objectives under consideration for the Tongue River below Tongue River Dam include fish passage at diversion dams and fish screening at canal inlet works.

Fish Passage

Dams throughout the world, constructed for whatever purpose by man (hydropower, flood control, irrigation, recreation) function as impediments to fish movements and migrations and have contributed to declines of fish populations by limiting access to habitat. Though great attention has been focused on needs and facilities for fish passage on major coastal rivers that support economically important anadromous fish runs,

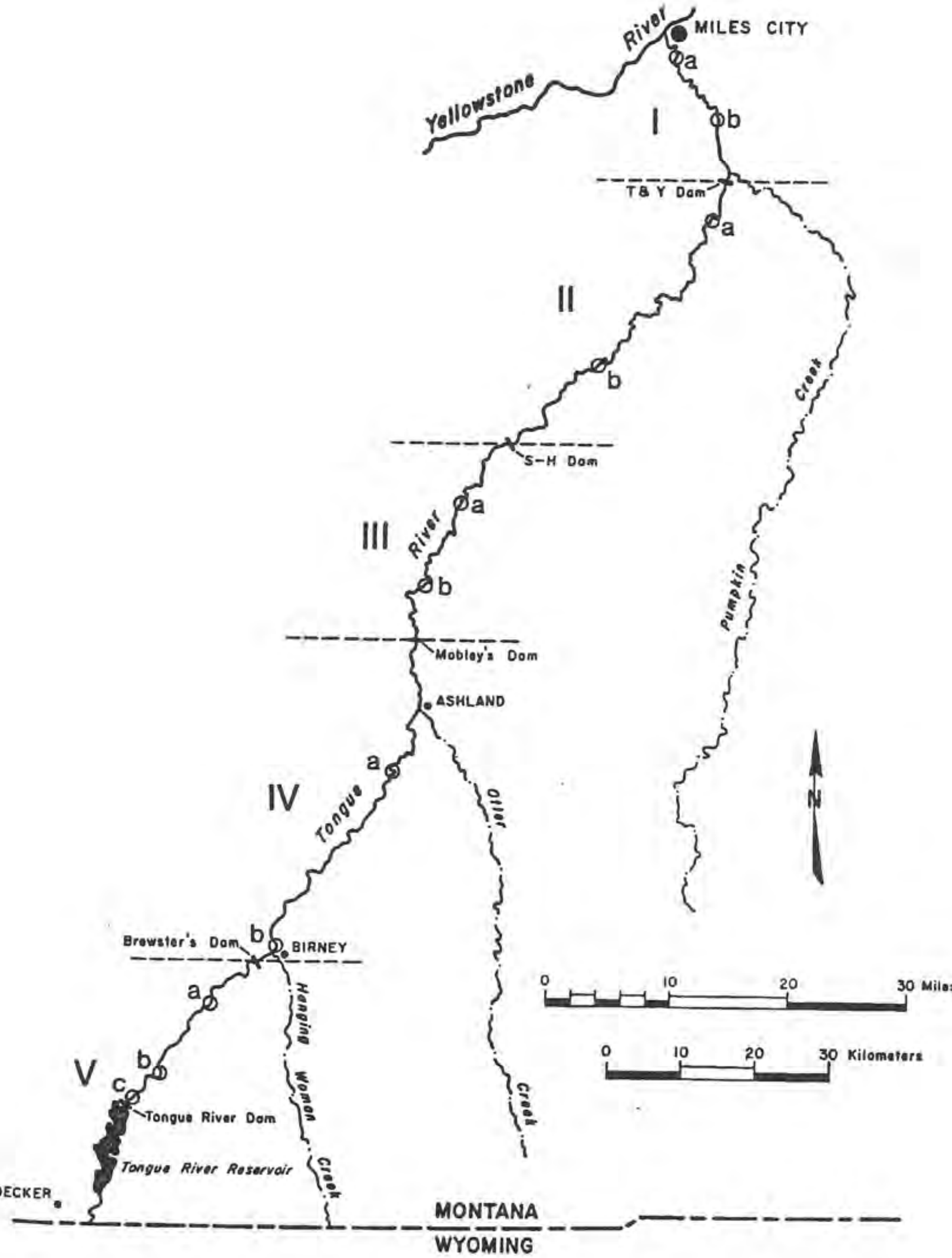



**Figure 1.** - Tongue River in Montana: major diversions, tributaries and sampling sections (reproduced from Elser and McFarland, 1977).

especially salmonid species, little attention has been given to fish passage needs at low-head diversion dams that dot western rivers by the hundreds. Recent declines of native western fish species have resulted in numerous listings of species threatened or endangered under both Federal and State laws. Indeed, western native fish species appear more vulnerable to human activities compared to species in other regions. During the past 100 years, some 21 species and subspecies among 6 fish families have become extinct from the 17 western states; some 64 species and sub-species from the western states are now Federally listed as threatened or endangered (Minckley and Deacon, 1992). Recognizing that diversion dams on the Tongue River may be limiting native and introduced sportfish populations, Reclamation's Great Plains Region contacted Reclamation's Technical Service Center, Denver, Colorado, to examine fish passage as a potential option for fishery enhancement associated with the Tongue River Dam Rehabilitation Project. The T and Y Dam, 20 miles upstream from the mouth on the Yellowstone River, may be limiting a number of native species including shovelnose sturgeon, sauger, goldeye, burbot, blue sucker, sturgeon chub, paddlefish, and potentially the rare pallid sturgeon. Diversion dams upstream from T and Y Dam no doubt limit movements of smallmouth bass and channel catfish populations, and would continue as impediments to other species that may be allowed passage around T and Y Dam.

The actual importance of movement restriction to fish population sizes in the Tongue River is not known, thus estimating the value of fish passageways would be problematic. Also, since no fish passageway can be expected to be 100 percent effective, any negative effects of the barriers now operating could not be 100 percent mitigated. Fish passageways may be beneficial to native species if spawning habitat is presently restricting populations, or if non-spawning habitat (i.e., feeding habitat) is limiting sizes of adult populations. On the other hand, if spawning or feeding habitat is not limiting present populations, or if passageways could result in negative interactions with introduced species, fish passage may be undesirable. Changes in river habitat above diversion structures, induced by flow controls from large dams such as the Tongue River Dam over the past several decades, may preclude these areas as habitat for the native species that once occupied the river reaches prior to dam construction.

Challenges associated with solving fish passage problems at diversion dams are serious and explain in part why there is little experience in this area either by fish passage researchers or resource managers. National attention was given to this issue at a recent interagency fish passage research priorities workshop held at the S. O. Conte Anadromous Fish Research Laboratory, Turners Falls, Massachusetts. It was generally recognized at the workshop that research data were very limited regarding fish passage of non-anadromous species. Government biologists from all regions of the United States presented needs for fish passage. Numerous research priorities were identified including the following:

1. Effective Upstream Fish Passage for Riverine Fish
2. Determine Actual Needs for Passage of Riverine Fish (Develop Much More Biological Data on Species of Concern)
3. Conduct Comprehensive Field Evaluations of Existing Fish Passage Facilities
4. Effective Downstream Passage of Riverine Species
5. Effective Barriers to Passage of Undesirable Species

6. Effective Upstream Fish Passage of Anadromous and Catadromous Fish (i.e., Sturgeon and Eels) Other Than Salmonids and Shad.

Clearly, no sound body of knowledge exists to provide definitive guidance on construction of fish passage facilities for native, riverine species. However, if there is consensus that fish passage would be beneficial, this should not preclude intelligent attempts, given that native fish species are generally in broad decline. Future fish passage considerations at western diversion dams would also need to include efficiency evaluations.

Fish Barriers at Canal Inlets

Fish can readily pass from the Tongue River into the canal outlets at all diversion dams during the irrigation season, though numbers, sizes and species composition are unknown. Potential losses of fishes to irrigation diversions in the west have been recognized many times in the past, and active fish protection programs have been in place in Washington, Oregon, California, and Idaho (Brannon 1929; Clothier 1953; Gardner 1941; Viox 1956; Wales 1948; Wray 1990). Bradshaw (1991) provided a good overview of the magnitude and means of reducing fish losses from off-stream diversions from a Wyoming perspective. Spindler (1955) analyzed and discussed fish losses related to physical characteristics of irrigation canal intakes on the West Gallatin River, Montana. Many factors can influence levels of fish losses into irrigation canals including: fish species, size, and river population sizes; location, construction, and manipulation of headgates; volume of flow; percent of river flow diverted; location of intakes in relation to river flow; temperature; and others. Bradshaw (1991) concluded that screening at irrigation intakes can be very effective, but can be very expensive. When fish protective measures are deemed necessary, alternatives to screening should also be considered such as fish deflectors, louvers, gradual reduction of flows at the end of irrigation seasons (to allow movement of canal fish back into the river), and removal of cover in canals near headgates. MDFWP has issued a pamphlet on "Methods to Reduce Trout Losses in Irrigation Diversions," emphasizing a gradual shutdown of canal flows following the irrigation season.

If fish passage is undertaken for the Tongue River, consideration should also be given to fish protection from canal entrainment. A recent study on the seasonal irrigation canals of the Shoshone Project in Northwestern Wyoming (Shoshone River) provided much insight into the potential for fish entrainment into these systems. A total of 5,732 fish of 11 species was collected from a combined 5 miles of three canals by electrofishing, block netting and draining techniques (Karp, et al. 1993).

## FISHERIES RESOURCES OF THE TONGUE RIVER

A number of fisheries investigations have been performed within the study area. The most extensive survey work was performed by Elser, et al. (1977) in a 2-year study to evaluate the impacts of water withdrawals and diversion structures on the migration, spawning, and rearing of fish populations from the Tongue River Dam to the confluence with the Yellowstone River (sections I-V, fig. 1). As part of a coal mining permit application, Clancy (1980) documented the status of fish populations in the Tongue River between Hanging Woman and Otter Creeks (river section IV). Backes (1993) surveyed fish populations in river sections IV and V to obtain pre-construction data as part of the Tongue River Dam Rehabilitation project.

The fisheries resources in the Tongue River within the study area demonstrate some faunal zonation based on temperature and habitat preferences of the resident species. Cold water releases from Tongue River Reservoir are sufficient to support small numbers of trout, primarily in the reach located immediately downstream from the reservoir. As the water warms, fish populations become more typical of prairie stream systems of this general latitude where the majority of fish belong to the sucker (*Catostomidae*) and minnow (*Cyprinidae*) families. The most common fish collected was the shorthead redhorse (*Moxostoma macrolepidotum*).

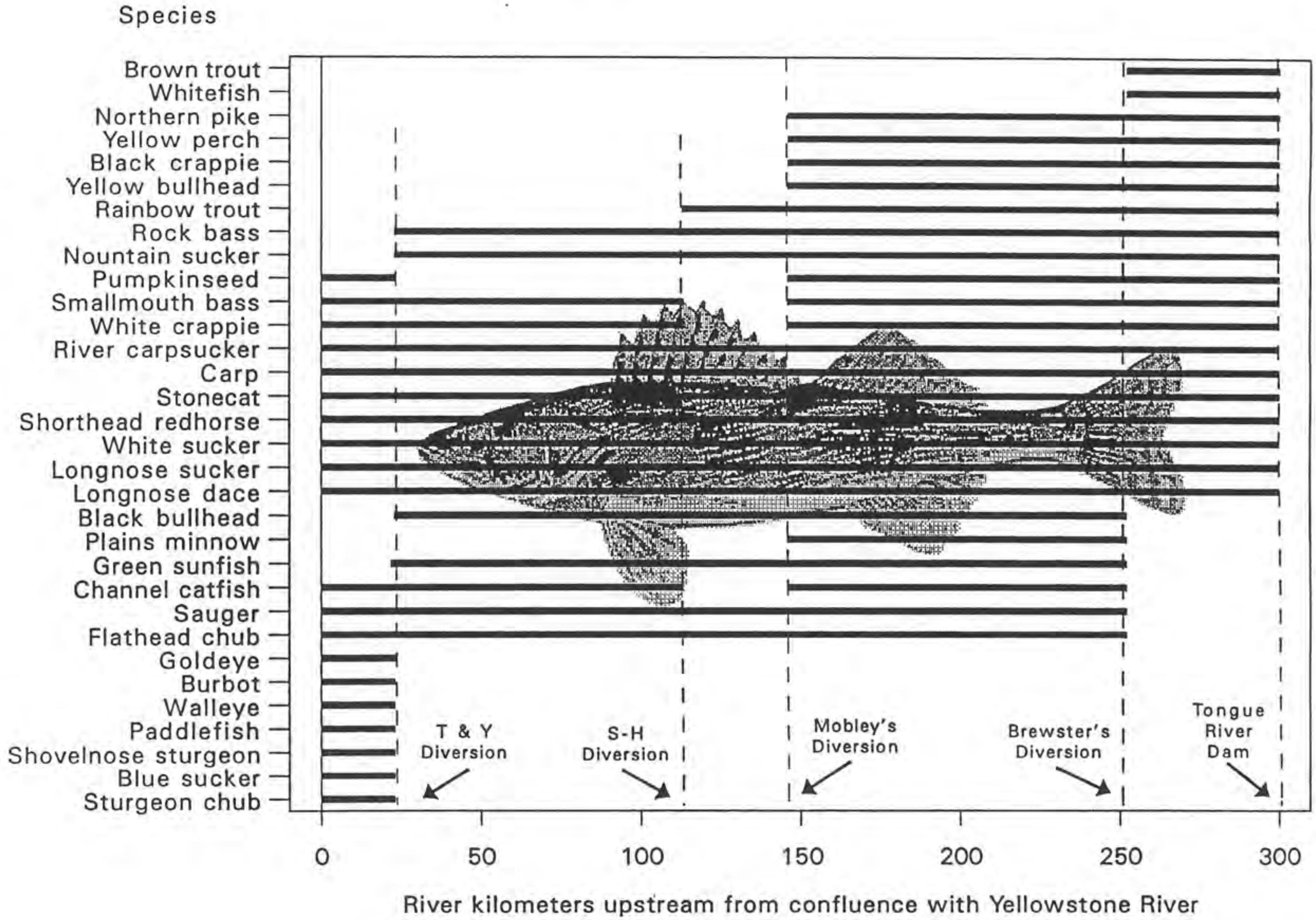
A total of 35 species have been reported to occur within the study area (Table 2). Of these species, burbot (*Lota lota*), paddlefish (*Polyodon spathula*), shovelnose sturgeon (*Scaphirhynchus platorhynchus*), and blue sucker (*Cycleptus elongatus*) were taken only in spring sampling downstream from the T and Y Diversion Dam (river section I) and were considered migrant species (Elser, et al., 1977). Other species confined to the downstream section are goldeye (*Hiodon alsoides*) and sturgeon chub (*Hybopsis gelida*). The T and Y Diversion Dam clearly influences the longitudinal distribution of these species by creating an impassable barrier to upstream migrations (fig. 2).

Other sport fish species found within the study area include sauger (*Stizostedion canadense*), channel catfish (*Ictalurus melas*), smallmouth bass (*Micropterus dodomieui*), rock bass (*Ambloplites rupestris*), and northern pike (*Esox lucius*). Smallmouth bass, rock bass and northern pike concentrations were highest in river section IV. Sauger concentrations were highest downstream from the T and Y Diversion Dam in section I. Elser, et al., (1977) reported the highest concentrations of channel catfish in sections I and II. Backes (1993) also found a high concentration of channel catfish in section IV at a location which had slow current, deep water (4 to 6 feet), scattered submerged logs, and a narrow river channel.

Table 2. List of Fish Species Reported to Occur in the Tongue River, Montana.

| Common Name | Scientific Name | River Sections | | | | |
|---|---|---|---|---|---|---|
| | | V | IV | III | II | I |
| Brown trout | *Salmo trutta* | ✓ | | | | |
| Whitefish | *Prosopium williamsoni* | ✓ | | | | |
| Northern pike | *Esox lucius* | ✓ | ✓ | | | |
| Yellow perch | *Perca flavescens* | ✓ | ✓ | | | |
| Black crappie | *Pomoxis nigromaculatus* | ✓ | ✓ | | | |
| Yellow bullhead | *Ictalurus natalis* | ✓ | ✓ | | | |
| Rainbow trout | *Salmo gairdneri* | ✓ | ✓ | ✓ | | |
| Rock bass | *Ambloplites rupestris* | ✓ | ✓ | ✓ | ✓ | |
| Mountain sucker | *Catostomus platyrhynchus* | ✓ | ✓ | ✓ | ✓ | |
| Pumpkinseed | *Lepomis gibbosus* | ✓ | ✓ | | | ✓ |
| Smallmouth bass | *Micropterus dolomieui* | ✓ | ✓ | | ✓ | ✓ |
| White crappie | *Pomoxis annularis* | ✓ | ✓ | | ✓ | ✓ |
| River carpsucker | *Carpoides carpio* | ✓ | ✓ | ✓ | ✓ | ✓ |
| Carp | *Cyprinus carpio* | ✓ | ✓ | ✓ | ✓ | ✓ |
| Stonecat | *Noturus flavus* | ✓ | ✓ | ✓ | ✓ | ✓ |
| Shorthead redhorse | *Moxostoma macrolepidotum* | ✓ | ✓ | ✓ | ✓ | ✓ |
| White sucker | *Catostomus commersoni* | ✓ | ✓ | ✓ | ✓ | ✓ |
| Longnose sucker | *Catostomus catostomus* | ✓ | ✓ | ✓ | ✓ | ✓ |
| Longnose dace | *Rhinichthys cataractae* | ✓ | ✓ | ✓ | ✓ | ✓ |
| Black bullhead | *Ictalurus melas* | | ✓ | ✓ | ✓ | |
| Plains minnow | *Hybognathus placitus* | | ✓ | | | |
| Lake chub | *Couesius plumbeus* | | ✓ | | | |
| Fathead minnow | *Pimephales promelas* | | ✓ | | | |
| Golden shinner | *Notemigonus crysoleucas* | | ✓ | | | |
| Green sunfish | *Lepomis cyanellus* | | ✓ | ✓ | ✓ | |
| Channel catfish | *Ictalurus punctatus* | | ✓ | | ✓ | ✓ |
| Sauger | *Stizostedion canadense* | | ✓ | ✓ | ✓ | ✓ |
| Flathead chub | *Hybopsis gracilis* | | ✓ | ✓ | ✓ | ✓ |
| Goldeye | *Hiodon alsoides* | | | | | ✓ |
| Burbot | *Lota lota* | | | | | ✓ |
| Walleye | *Stizostedion vitreum* | | ✓ | | | ✓ |
| Paddlefish | *Polyodon spathula* | | | | | ✓ |
| Shovelnose sturgeon | *Scaphirhynchus platorhynchus* | | | | | ✓ |
| Blue sucker | *Cycleptus elongatus* | | | | | ✓ |
| Sturgeon chub | *Hybopsis gelida* | | | | | ✓ |

Data compiled from Backes, 1993; Clancy, 1980; and, Elser, et al., 1977.




Data compiled from Elser and McFarland, 1977 and Backes, 1993.

**Figure 2.** Longitudinal distrobution of fish in the Tongue River, Montana with respect to diversion structures creating potential barriers to passage.

Resident Fish Migration Patterns

Adult Fish - A number of studies have documented the migration patterns of adult fish found in the study area including northern pike, smallmouth bass, sauger, shovelnose sturgeon, and channel catfish. Resident northern pike populations in section IV move into the lower portions of Hanging Woman Creek during April and May to spawn (Clancey, 1980). Elser et al. (1977) reported the presence of small northerns (<0.77 feet in length) suggesting that these fish were successfully reproducing in this portion of the basin. Smallmouth bass populations in this section have also been shown to exhibit long distance seasonal migrations at two specific times of year (Clancey, 1980). During April and May, fish larger than 0.98 foot move upstream, some as far as 50 miles. By September and October, these fish had moved back downstream, with a high proportion taking up winter residence in a short reach of river containing boulder substrate. Langhurst and Schoenike (1990) reported similar migration patterns in temperate populations of smallmouth bass in the Embarrass and Wolf Rivers in Wisconsin. Age-two fish (>0.65 foot in length) began downstream migrations ranging as high as 68 miles in the fall when water temperatures fell below 60.8 °F. Although no specific overwintering areas were found, the authors theorized that paucity of deep pool habitat in the upper rivers and the severity of winters in northern latitudes made migration of adult smallmouth to deeper water of a larger river or lake necessary for survival. The majority of adult fish tended to return each spring to the same upstream area by mid-May as water temperatures neared 59 °F.

River section I has been documented as an important spawning area for sauger and shovelnose sturgeon. Also, the endangered pallid sturgeon (*Schaphirhynchus albus*) may still enter the lowermost reach of the Tongue River during periods of high runoff (FWS, 1992). Sauger are found moving out of the Yellowstone River and into the Tongue from March to June. Spawning generally occurs in areas with gravelly or rocky substrate when water temperatures reach 40-50 °F. The spawning migration for shovelnose sturgeon begins around the first of May with spawning occurring from early June until mid-July. Elser, et al., (1977) found the optimum spawning temperature for shovelnose sturgeon in the Tongue River to range from 60 °F and 70 °F.

Larval and Juvenile Fish - Little information on larval or juvenile fish was reported in the three reports on fisheries surveys in the Tongue River. Clancey (1980) did report that upstream sections generally supported larger numbers of large fish. For nearly every species, larger individuals were found in the upstream sections and small individuals in the downstream sections. It was hypothesized that this was the result of downstream drift of larval fish during the spring, following spawning, with subsequent movement of fish upstream as they grow and mature.

## BIOLOGICAL CONSIDERATIONS IN PROVIDING EFFECTIVE FISH PASSAGE

Migration is an important feature of the biology on many fish species which have been adversely affected by water impoundments and water use. The task of minimizing the effects of these uses on fish populations is complex and requires close cooperation between planners, biologists, engineers, and decisionmakers. The full breadth of a species' life history should be examined before fish passage facilities are considered. When considering the entire fish community, the often variable requirements of the individual species present also tends to make comprehensive solutions more complicated and difficult to quantify. However, there are certain consistencies based on the behavior and biology of the fish species which can provide a framework for evaluation of potential solutions. Effective solutions require considerable knowledge about these factors. In light of the limited information in these areas as it relates to the fish species present in the Tongue River, it seems useful to review some basic concepts as they relate to facilities designed to assist in upstream (adult) migration and in the protection of downstream (larval and juvenile) migrants.

### General

The phenomenon of migration, although manifested to different degrees, is characteristic of both anadromous and semi-anadromous fish, as well as for some species which live only in freshwater. The common biological significance of all migrations is that they provide complex use of the full range of potential habitats according to a species changing requirements at different stages of its life cycle. The scale of migrations is determined by evolutionary and species-specific requirements, and in modern times, by manmade alterations to the aquatic systems where these species reside (Pavlov, 1989).

In rivers, fish migrations are associated with currents, although during the life cycle, the direction of fish movement with respect to the current often changes. For individual species, active migrations against the current (spawning migrations) generally occur together with passive (drift of eggs, larvae, and fry), or active-passive migrations of juveniles or recently spawned brood stock. Often, highly variable and adaptable strategies have developed in order for species to cope with complexity of the environmental variables which have been shown to influence migration (streamflows, temperature, turbidity, ambient light levels, etc.). Understanding the spatial and temporal characteristics of migrations as they relate to environmental variation and fish population dynamics will become increasingly important if resource managers are to prevent the continued decline of aquatic communities in the future.

### Rheoreaction in Fishes

In a water current, fish usually orient themselves and move into the current. This behavioral phenomenon is known as rheoreaction and includes both orientational and locomotory components. Fish orientation into the currents is primarily accomplished through the use of optical and tactile sensory systems. The dominant orientation mechanism for an individual species may change depending on life stage or environmental conditions. For young fish that rely on the visual mechanism as the primary means of determining orientation, drifting with the current often occurs when illumination levels fall below the threshold for the optomotor response (Pavlov, 1989).

The locomotory activity of fish has several functional indices, which are useful in describing a fish's behavior and physical abilities as it relates to migration and passage past hydraulic works. Threshold velocity is the minimum current velocity which leads to an orientation reaction against the current (Pavlov (1989) reported values ranging from 1-30 $m^3/s$). It is important to maintain threshold velocities in order to maintain the migratory behavior desired. Often, if flows are excessively turbulent or low, fish may become disoriented relative to the main flow and be delayed in their migrations. Critical velocity is the minimum current velocity at which fish begin to be carried away by the waterflow. For upstream migrants, flow velocities less than the critical value must be maintained in order to allow passage. For downstream migrants, critical velocities are often exceeded to ensure that young fish do not become excessively delayed in civil works such as bypass structures.

Another aspect of locomotory activity, which is important in the design of fish passage facilities, is a fish's swimming ability. Swimming performance is the duration of active swimming as a function of a fish's speed. The greater the speed, the lower the duration of time this movement can be maintained. In the development of fish passage structures, three aspects of swimming speeds are of concern:

- cruising - a speed that can be maintained for long periods of time (hours);
- sustained/maximum - a speed that can be maintained for minutes; and,
- darting/burst - a speed that can be achieved in a single effort but cannot be maintained.

Fish normally employ cruising speed for normal movements such as migrations, cruising/maximum speeds for passage through difficult areas, and darting/burst speeds for escape or feeding purposes (Bell, 1990).

Integrating the Biology and Engineering

To be effective, any fish passage facility must consider the behavioral and physical abilities of all life stages of the fish species which require assistance passing the structure. When considering the population as a whole, engineering challenges may arise due to the diversity of requirements which different species may present. During the evolution of fishes, two main behavioral strategies were developed, that of pelagic and benthic fishes. Typically, in pelagic species, the visual mechanism is dominant in determining orientation, they tend to be fairly uniformly distributed in the flow and located in the upper portion of the water column, and exhibit low threshold velocities and high critical velocities. Benthic species, on the other hand, generally orient themselves based on tactile mechanisms, tend to concentrate along stream margins or in other suitable velocity zones, and exhibit high threshold velocities and low critical velocities. Historically, fish passage facilities have usually concentrated on a single species such as salmon, with the assumption that if suitable passage conditions can be provided for this species, others will also benefit. To a certain degree this is true for species with similar life history and locomotory patterns. However, the presence of both pelagic and benthic species provide unique biological, engineering, and management challenges.

GENERAL RIVER HYDRAULICS AND FISH PASSAGE CONSIDERATIONS

River Hydraulics

There is substantial uncertainty as to future instream flows in the Tongue River below the T and Y Diversion Dam. As documented in the Tongue River Water Model Draft Report, GoeResearch-1991, on instream flows, future water use by Wyoming and the Northern Cheyenne Tribe are critical factors to establishing sufficient spring and mid-summer flows for sturgeon and sauger spawning in the river reach below the T and Y Diversion Dam. The DFWP recommendations given in table 1 are the target instream flows given sufficient river water is available. Obviously, riverflows will vary substantially depending on winter snowpack and summer irrigation demands. Knowledge of probable Tongue River flows in relation to storage and water use demands along the river's length is important to identifying effective fish passage opportunities.

Several river model studies were conducted by Montana Department of Natural Resources and Conservation (Anderson, 1990; GeoResearch, 1991) to estimate likely instream flows below the T and Y Diversion Dam. These studies show future additional water use by Wyoming and the Northern Cheyenne Tribe are pivotal issues to meeting the desired instream flows. Should Wyoming and the Northern Cheyenne Tribe exercise their full water rights, instream flows below the T and Y Diversion Dam will fall short of meeting the desired spawning flows in many water years, figure 3.

There are four irrigation diversion dams on the Tongue River below the Tongue River Reservoir, Table 3.

Table 3. List of water diversion dams on the Tongue River.

| Diversion Dam | *Water Right ($ft^3/s$) | Estimated Height of Diversion Dam (ft) | Approximate River Mile Location Above Miles City |
|---|---|---|---|
| T and Y | 237.5 | 10 | 20 |
| S-H | 62.3 | 5 | 85 |
| Mobley's | 29.3 | Unknown, assumed value of 5 | 105 |
| Brewster's | 3.2 | 4-5 | 160 |

The T and Y Diversion Dam, figure 4, is lowest on the river and the largest diversion. Therefore, during the irrigation season instream flows above the T and Y Diversion Dam are substantially higher than below the dam.

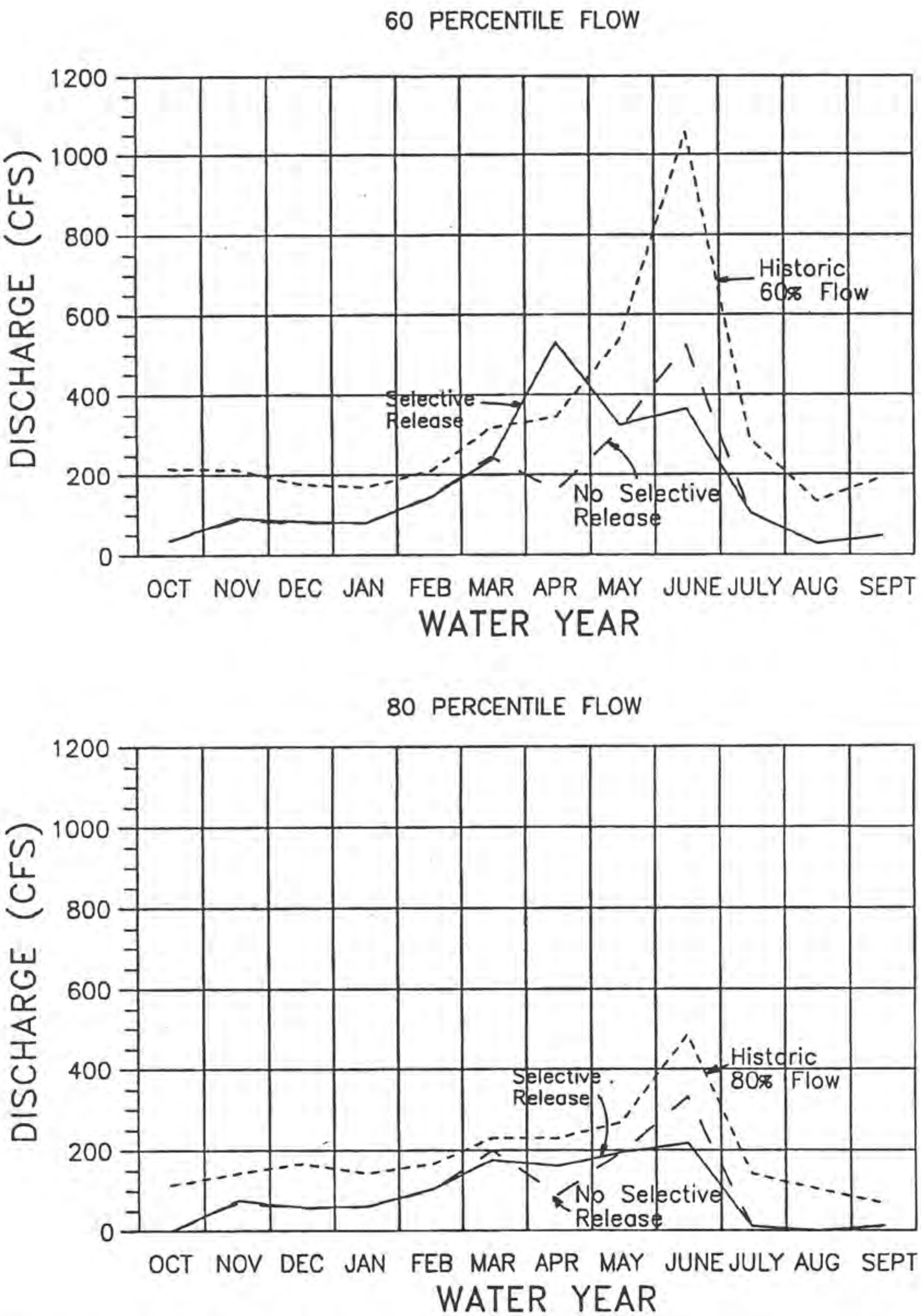



**Figure 3** - Tongue River discharge at Miles City assuming all Wyoming water used.

**Figure 4** - T and Y diversion dam, Tongue River, Montana

## Fish Migration Barriers

All four diversion dams are small overflow weirs which operate as run-of-river structures, providing no usable storage. Diversion dams like those on the Tongue River are intended to serve as artificial gradient controls on the river, raising the upstream water level sufficiently to allow gravity diversion, in this case, into adjacent irrigation canals. Overflow diversion dams alter the normal river gradient by concentrating natural elevation drop at the dam. For example, the T and Y Diversion Dam causes an elevation drop of about 10 feet over a river distance of roughly 30 feet. By comparison, the river where the dam is located has a natural stream gradient of about 0.0006 ft/ft.

The action of flow passing over the dams is illustrated on figure 5. The rapid acceleration of flow passing over a dam and the turbulent eddies created in the flow/tailwater impingement zone act individually or collectively to inhibit fish passage. These flow conditions are particularly effective barriers to native species indigenous to low gradient streams like the Tongue River. The fishery habitat exclusion currently imposed by these small diversion dams on the river is illustrated in the findings of the Yellowstone impact study (Montana Department of Natural Resources and Conservation, 1977). The study lists 31 species of native and exotic fish found in the Tongue River. Of the 31 species, 7 species were found solely in the river reach below the T and Y

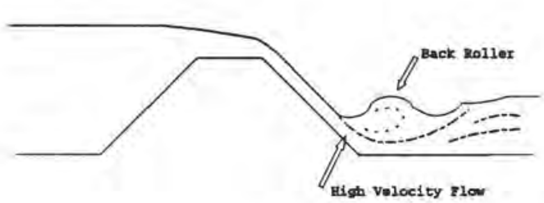



**Figure 5** - Flow conditions downstream of an overflow dam.

Diversion Dam. These species were: goldeye, burbot, walleye, paddlefish, shovelnose sturgeon, blue sucker, and sturgeon chub. The study also found population densities below the T and Y Diversion Dam are much higher than upstream for many other native species like the sauger.

Opportunities for Fish Passage

There are numerous types of fish passage structures designed to allow migrating fish species to move both upstream and downstream bypassing dams that otherwise form barriers limiting natural habitat. Most structures that have proven effective, target specific fish species, like salmonids. The structure must complement the physical swimming strength and behavioral characteristics of fish it serves. The vast majority of the research and implementation of fish passage structures is focused on passage of salmonids which are strong swimmers. By comparison, the swimming strengths of native species found in the Tongue River are relatively weak.

Swimming ability and habitat preference of many of the fish species native to the Tongue River were studied by Schmulbach, Tunink, and Zittel (1982). Swimming performance tests were conducted to determine sustained swimming speed, critical swimming velocity, and short-term burst speeds of species endemic to the Missouri River. There are considerable differences within the literature concerning the time duration associated with these definitions. Sustained swimming speed is generally defined as the maximum sustained swimming speed for durations of about 3 hours. Critical swimming velocity can be thought of as the flow velocity at which the fish are carried downstream by the flow. This corresponds to a fish's maximum sustained swimming speed for a duration of about 0.1-1.0 hour. Burst speed is typically defined as short term, < 15 second duration, maximum attainable swimming speed.

Table 4 provides swimming performance data for several species of interest on the Tongue River.

Table 4. Swimming abilities of several fish species native to the Tongue River.

| Fish Species | Maturity | Critical Velocity (ft/s) | Sustained Swimming Speed (ft/s) | *Estimated Burst Speed (ft/s) |
|---|---|---|---|---|
| Paddlefish | Immature | 1.9 | Unknown | - |
| Shovelnose Sturgeon | Adult | 2.5 | 1.8 | 5.4 |
| Goldeye | Adult | 2.6 | 2.2 | 6.6 |
| Blue Sucker | Adult | 2.6 | 2.3 | 6.9 |
| Sauger | Adult | 1.9 | 1.5 | 4.5 |

* Burst speeds are estimated to be 3 times the sustained swimming speed.

In addition to swimming capability, understanding habitat preference is also important to determining opportunities for fish passage. Schmulbach, Tunink, and Zittel (1982) found preferred habitat for the paddlefish, shovelnose sturgeon, and blue suckers are pool areas along main channels where current velocities average about 1.0 ft/sec, roughly half of their sustained swimming speeds. Paddlefish were also frequently found in backwater areas. These data compare with observations made by Hurley (1983), and Tongue River shovelnose sturgeon capture data given by the Yellowstone Impact Study, 1977, figure 6. The majority of the fish captured were in the main thalweg. The capture position across the river is skewed showing favor for the milder sloping channel bottom. This cross-channel distribution may reflect a velocity limiting condition on the right side of the channel. The steeper cut bank on the right side of channel is indicative of higher velocity flow. Additional insight can be gained by examining the sturgeon's food source habitat. The Yellowstone study found shovelnose sturgeon primarily feed on larval invertebrates which prosper in riffles with velocities in the 1- to 2-ft/s range.

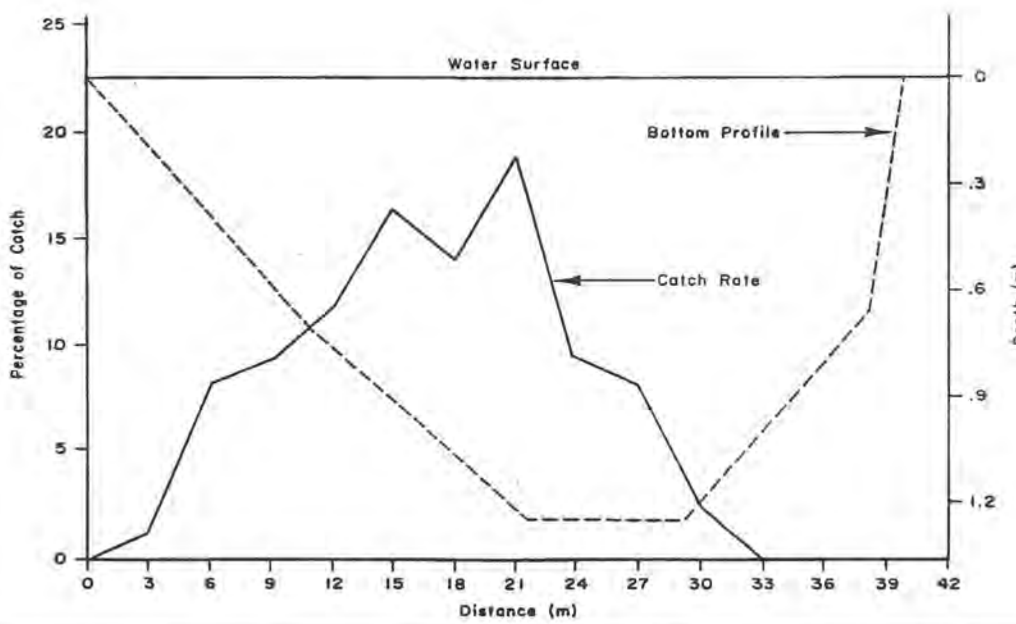



**Figure 6** - Comparison of catch rates of shovelnose sturgeon with bottom profile based on 1975-1976 sampling at a site below the T&Y dam on the Tongue River.

The goldeye and the sauger show little habitat preference, Schmulbach, Tunink, and Zittel (1982). They are commonly found in turbid slow moving areas of the main channel, in pools and backwater.

Fish Passage Attraction and Search Zone

Combined operation of the fish bypass and the flow over the dam must produce attraction flows that move fish to the entrance of the fish passage structure. Pavlov (1989), found cross-channel flow distribution, mean velocity of the search zone, and alignment of fish passage with respect to the dam all affect the performance of fish bypass attraction flows. Acting together, flow distribution and the mean velocity of the flow below the dam dictate the fish search zone. In cases where the dam overflow is nearly uniform across the channel and the velocity below the dam is greater than the fish critical swimming velocity, fish will likely crowd to the channel edges. If average velocities are less than critical swimming speeds, fish will search along the dam toe for passage. The entrance to the bypass downstream of the diversion dam must also be positioned in relation to fish critical swimming velocity. If velocities at the toe of the overflow dam are sufficiently above the critical swimming velocity, the entrance to the fish bypass must extend downstream until the flow slows to near the critical swimming velocity. A short fish pass entrance is preferable if flow velocities below the dam are less than critical.

Several studies referenced by Pavlov also show the importance of alignment of attraction flows and riverflows. These studies show it is desirable to align attraction flows and riverflow as parallel as possible. This avoids creating converging flows that create large eddies and slack water zones to the sides of the attraction flow. Such flow conditions often deter migrating fish from finding passage structures.

Flow Conditions Below Tongue River Diversion Dams - Proper design of attraction flow requires knowledge of the flow conditions immediately downstream of the diversion dams. Currently, this information must be estimated based on visual observations of the structures, area topography, and discussions with local residents. No structural information is available for the four Tongue River diversion dams.

A separate appraisal of flow conditions downstream of the T and Y Diversion Dam is given due to its height. Flow conditions downstream of S-H, Mobley's, and Brewster's Dams are considered to be similar.

The T and Y Diversion Dam spans the river channel a distance of about 300 ft. The dam is aligned nearly normal to the channel rising about 10 feet high. Discharge per unit width across the dam crest appears to be uniform, thus producing an even distribution of overtopping flow across its width. For the purposes of this feasibility study, estimates of the current flow conditions at the T and Y Diversion Dam are given in Table 5. Flow conditions estimated for the upper three diversion dams are given in Table 6.

Table 5. Hydraulics of flow over the T and Y Diversion Dam.

| Discharge Passing the Dam ($ft^3/s$) | Unit Discharge, per foot of width, ($ft^3/s/ft$) | Depth of Flow on the Crest (Critical depth) (ft) | Estimated Velocity of Flow at Impingement with the Tailwater (ft/s) | Estimated Depth of Flow at the Impingement with the Tailwater (ft) |
|---|---|---|---|---|
| 200 | 0.7 | 0.4 | 14.5 | 0.05 |
| 600 | 2.0 | 0.75 | 19.0 | 0.10 |
| 1000 | 3.3 | 1.0 | 21.0 | 0.16 |

**Figure 7** - Flow over the S-H irrigation diversion dam on the Tongue River.

Diversion dams upstream of the T and Y Diversion Dam are smaller in height, each estimated to provide roughly 5 feet of water surface differential. The S-H Diversion Dam provides the second largest diversion on the river, figure 7. Although no structural information is available on the dams, visual observations of flow conditions at S-H Diversion Dam clearly show highly non-uniform flows across the crest. Substantially more flow passes over the left side (looking downstream) of the structure due to a lower crest height. An upstream gravel bar and debris wedged on top of the dam restrict overflow near the center of the channel. Non-uniform flows will often alter the search zones of migrating fish by creating high-velocity chutes, eddies, and slack water areas.

Table 6. Hydraulics of flow over S-H, Mobley's, and Brewster's Diversion Dams.

| Discharge Passing the Dam ($ft^3/s$) | Unit Discharge, per foot of width ($ft^3/s/ft$) | Depth of Flow on the Crest (Critical depth) (ft) | Estimated velocity of flow at impingement with the tailwater (ft/s) | Estimated depth of flow at the impingement with the tailwater (ft) |
|---|---|---|---|---|
| 200 | 0.7 | 0.4 | 12.4 | 0.05 |
| 600 | 2.0 | 0.75 | 14.4 | 0.14 |
| 1000 | 3.3 | 1.0 | 15.1 | 0.22 |

Passage Flow Velocity Criteria

Swimming speed limitations of the Tongue River fish species are the primary criteria for fish passage design. Flow velocities within the fish pass should not exceed the fish critical swimming velocity when possible. If flow velocities of greater than critical swimming velocity are incorporated, these zones must be of short length and low-velocity resting zones must be provided on each end of the high-velocity zone. At no point along the passage route can the flow velocities exceed the burst swimming speed of the targeted fish species. As burst swimming speeds of many of the Tongue River species are poorly documented, passage designs should use conservative estimates of burst speeds. General criteria for fish passage of Tongue River fish species should be: desired passage velocity = 2.0 ft/s, maximum passage velocity = 4 ft/s for a maximum distance of 10 ft.

Fish Passage Installations

Several types of fish passage structures exist that have proven effective for passage of weak swimming species. A common type of fishway is the fish lift or fish lock concept. These types of structures operate similar to a ship lock. Fish enter a capture chamber following attraction flow. A reciprocating control gate closes the chamber, trapping the fish. Water continues to enter the chamber raising the water surface until the level of the upstream reservoir is attained. A typical Borland-style fish lift developed in Scotland is shown in figure 8, British Engineering (1950). Borland lifts have been used for passage at both small and large dams.

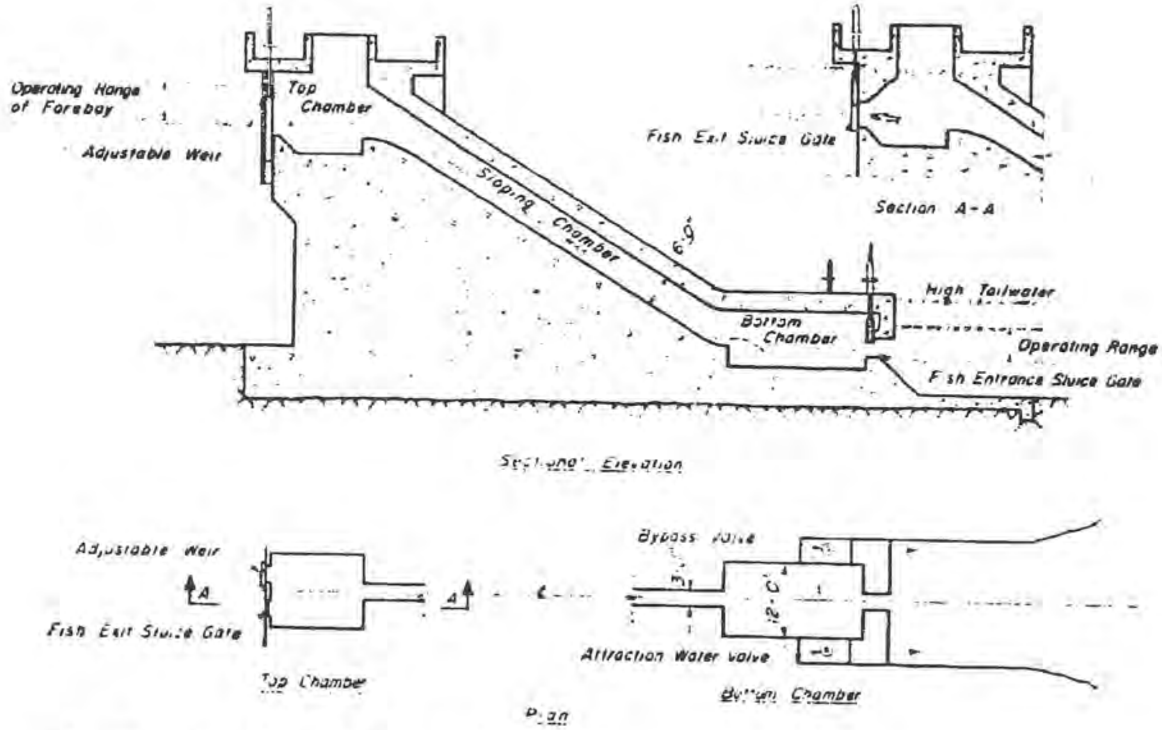



**Figure 8** - Elevation view of a Borland fish lift.

Weir-type fish ladder designs can also be effective for non-salmonids passage. Prototype studies of two Denil ladders on the Fairford River, Manitoba and Cowan Lake, Saskatchewan (Katopodis, et al., 1991) found the ladders provided effective passage for sauger, walleys, white suckers, and other resident fish species. The Denil ladders are designed at a 12 percent slope with run lengths of between 15 and 30 ft, figure 9. The ladders have a total elevation drop of about 7 ft. At Fairford, velocities in the weir chutes varied from about 4.5 ft/s at 0.6 depth to about 2.3 ft/s at 0.2 depth. Slightly higher velocities were measured at Cowan Lake. The velocities are above reported critical swimming velocities of many species using the ladders. However, velocities were below burst swimming speeds. Weak swimmers were assumed to pass up the Denil ladders by holding close to the bottom in the lowest velocity zone. Documentation showed nearly all fish using the ladders were adults. Unfortunately, the study did not compare ladder usage to downstream fish populations. Therefore, the study results do not clearly show the overall effectiveness of the ladders. A previous Canadian study by Schwalme and Mackay (1985), of two Denil ladders and a vertical slot ladder, figure 10, found similar results to Katopodis's. The Schwalme and Mackay study also found the vertical slots provide slower passage velocities compared to a Denil. Although the data are not conclusive, juveniles and weaker swimmers appeared to prefer the vertical slot ladder.

Fishways may also be constructed as bypass channels skirting the abutments of low dams. The dam elevation drop is typically overcome by the summation of multiple small

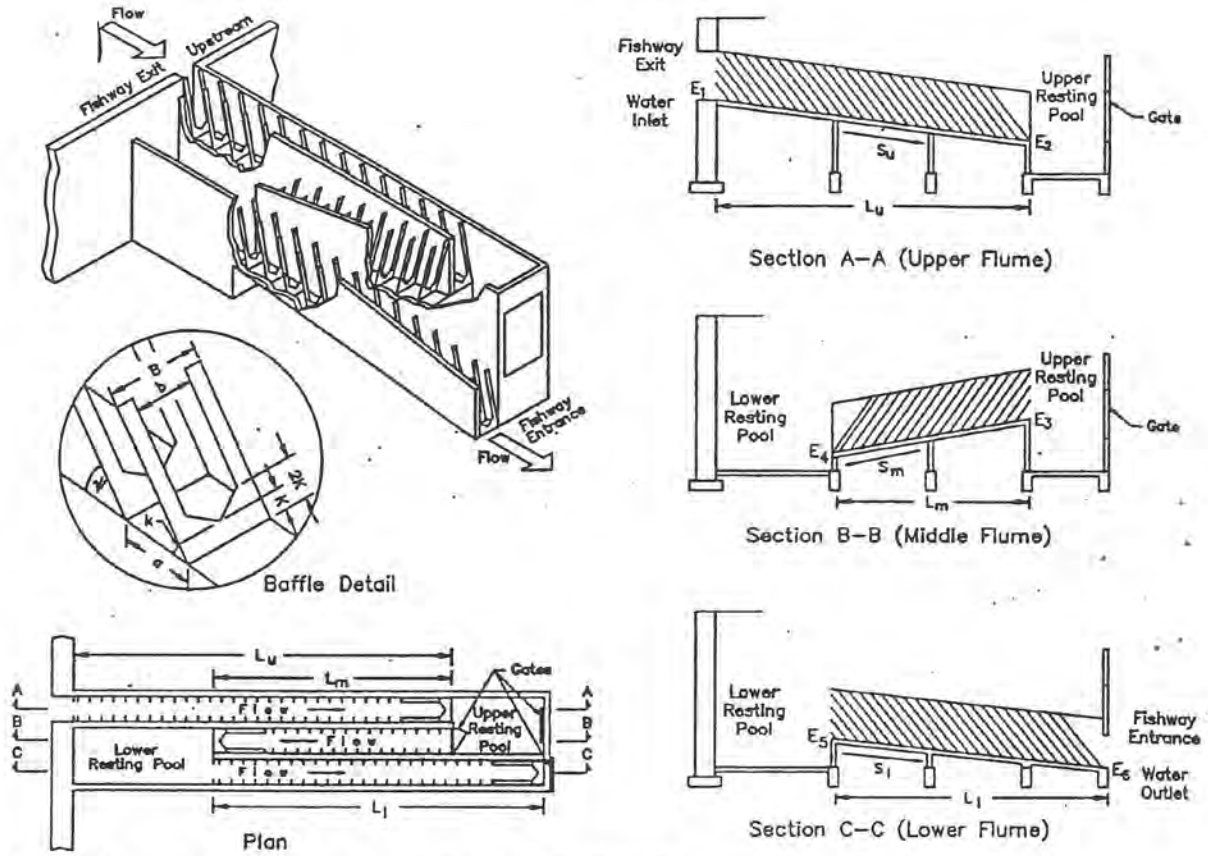



**Figure 9** -Denil fishways installed at Fairford and Cowan, Canada.

drops installed along the bypass channel. A typical low sill and pool fishway is shown in figure 11. Low sills can be constructed as walls (as shown) or as sloping ramps. If bottom swimmers are resident, the ramp-type sills offer less barrier to the vertical walls. In some cases, low dam applications of sill-type passage structures can be implemented using a series of rock ramp drops connected by pools. Large rocks provide natural resting areas for fish traversing the channels.

Fish Passage Recommendations

All of the passage structures discussed could be designed to provide fish passage for diversion dams on the Tongue River. Each has benefits and problems that must be considered for the Tongue River applications. Selection of a fish passage must consider potential effectiveness given dam heights, existing water rights, and river stage fluctuations. Additional selection concerns are: costs of construction, maintenance and debris handling, and operation costs. These issues will be discussed for each of the three fishways presented.

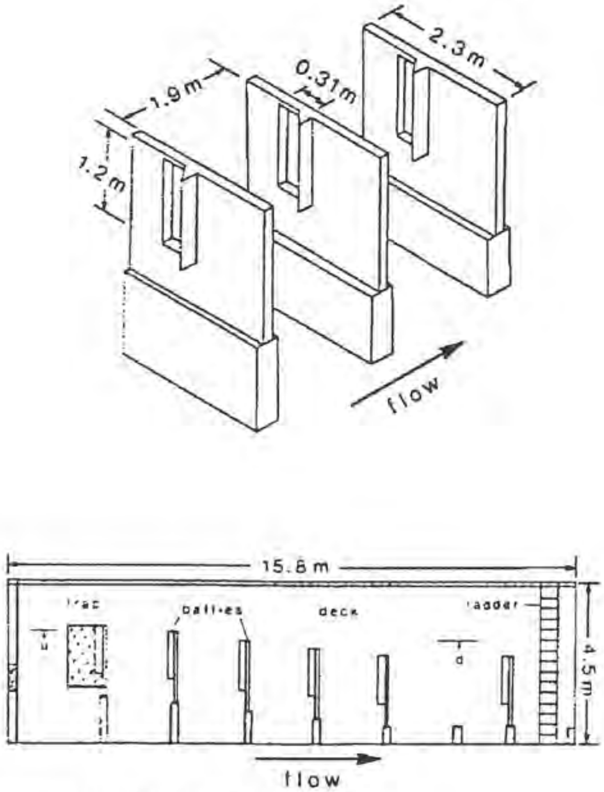



**Figure 10** - Vertical slot fishway

Fish Locks - Many operating fish locks are documented by Pavlov (1989) and Quiros (1989). Studies show the locks are effective and produce low stress during passage. Locks nearly negate limitations of fish swimming speed and endurance, and therefore can provide passage for a wide range of species and life stages. Due to dam height constraints, most documented locks have enclosed attraction chambers and locks. The effectiveness of enclosed locks often suffers from poor attraction conditions in the capture chamber. Several studies cite fish avoiding entry into the capture chamber due to low light conditions and small attraction flows. Attraction problems can be avoided by using a free surface lock design for the low Tongue River diversion dams, figure 12. This type of design could be implemented using a commercially available overshot leaf gate pivoting on the chamber floor. During an attraction period, the gate lies on the chamber floor in the down position. Raising the gate increases the water level in the attraction chamber until the level of the upstream water surface is reached. Overshot gates are available which use air bladders to raise and support gate leaves, thus requiring minimal mechanical installation and operation costs. These types of gates are commonly used on dams for low head (< about 15 ft) regulation.

This type of fishway could be placed anywhere along the dam crest. Design of fishway width and discharge are extremely flexible, thus allowing a wide fishway structure for optimum attraction flow that will not impact existing water rights during low flow periods. Debris and sediment carried by the river will pass through the fish lift without special maintenance concerns. Cost estimates for a 10-ft-wide fish lift for the T and Y dam are:

| |
|---|
| Assume reinforced concrete structure 10-feet wide, 10-feet high, 1.5-ft thick, and 25-ft-long walls, 10-ft-deep footings, 1-ft-thick floor slab |
| Design, staging, and bulkheading (Dewatering is assumed to be minimal for fall construction) . . . . . . . . . . $25,000 |
| Excavation and concrete placement . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 65 yards @ $500/yd placed, $33,000 |
| Overshot gate and air system (Cost based on use of an Obermeyer gate) . . . . . . . . . 100 ft² @ $300/ft², $30,000 |

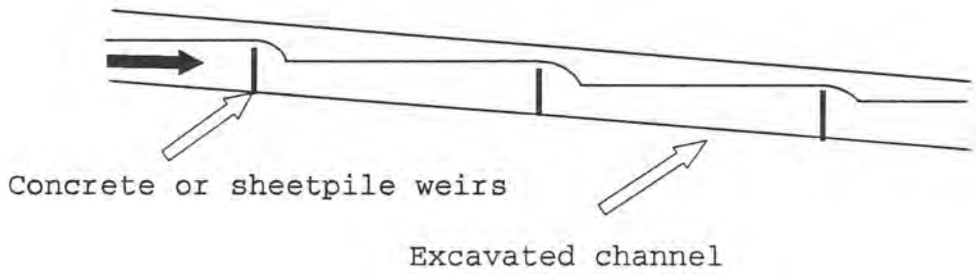



**Figure 11** - Low sill and pool fishway.

Total estimated cost for constructing the 10-ft-wide, 10-ft-high, fish lift is \$88,000. The cost estimate will vary based on site foundation materials and predicted scour depths below each dam. Operation of the lift will require power for intermittent operation of a 200 $ft^3$ at 10 $lb/in^2$ air compressor during the irrigation season. Cost of a fish lift for a 5-ft-high dam would be approximately 60 percent of the above cost, \$53,000.

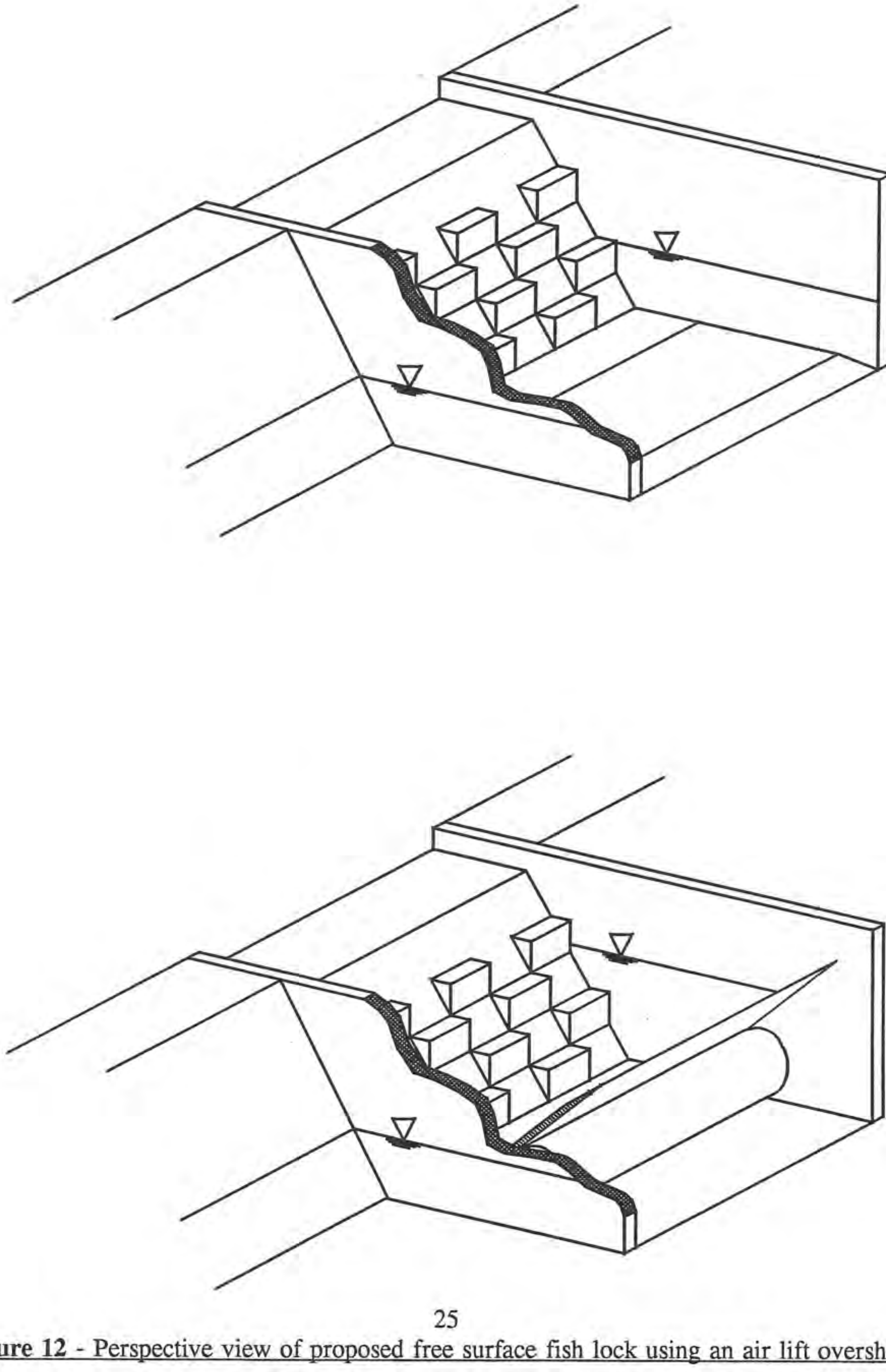




**Figure 12** - Perspective view of proposed free surface fish lock using an air lift overshot gate.

Denil or Slot Type Ladders - The Canadian studies discussed provide good documentation of non-salmonid fish passage through weir-type ladders for low diversion dams. Based on their results, a weir ladder should provide effective passage for fish capable of burst swimming speeds of about 4.0 ft/s or greater. The relatively high fishway velocities will likely exclude juveniles and some small adult species. Consideration must be given to the attraction flows and placement of the ladder with respect to the river channel. The entrance to the fishway will likely require notching the dam crest at the flow entrance to the fishway by 1 to 2 feet to attain desired fishway flow. Provisions for stoplogging the crest may be needed to adjust fishway operation during high river flows and ensure existing water rights are protected during low river flows. Weir-type ladders also require debris protection and removal methods. A coarse trashrack is required in front of the upstream end of the fishway to prevent large brush or trees from entering the weir lattice. Rainey (1991) suggests debris loading and handling is frequently underestimated by fishway designers. Historical river debris loading needs to be given a high priority in any fishway design. Debris removal also requires good access to the fishway under all normal flows. This limits placement of weir type ladders to near the channel banks. If debris loads are heavy during high flow periods on the Tongue River, specialized debris removal equipment can be installed as a part of the fishway. Light debris loads may only require occasional trashrack cleaning with a backhoe. Sediment passage through ladders has not caused operational problems in the cited literature. However, the potential for deposition of sediment in the attraction zone downstream of the fishway should be recognized and avoided by proper placement of the fishway in relation to channel flows.

For major diversions like the T and Y and S-H Diversion Dams, fishways should be placed to the opposite side of the river from the diversion canals. Fishway placement near the diversion intake would result in canal entrainment of many fish exiting the fishway.

A ladder designed at a 12 percent grade (similar to the Canadian ladders) requires run lengths of about 42 feet for a 5-foot elevation rise and 84 feet for a 10-foot rise. As shown in figure 9, the Fairford and Cowan fishways shorten the total run length by using multiple runs with connecting resting pools similar to a stairway alignment. A fishway for the T and Y Diversion Dam could be designed with three 28-ft-long runs or five 17-ft-long runs. A five-run design would be preferable for weaker swimmers. However, costs and fishway entrance positioning are additional factors affecting structure design. Due to the considerable lengths required for low gradient fishways, fishway passage widths would likely be limited to about 3 to 5 ft. Passage flows for this size of fishway would be about 5 to 10 $ft^3/s$ depending on river stage. For the Tongue River, attraction flows exiting a ladder-style fishway will frequently be small in comparison to adjacent dam overtopping flows. To achieve best attraction, the ladder should be placed near the edge of the river thalweg. Therefore, cross-channel positioning of a ladder must consider access, achieving effective attraction flow, and potential sediment deposition in the attraction flow area.

Costs for construction of Denil or slot-type weir ladders were not found in the literature search conducted for this report. The Manitoba Department of Natural Resources, Fisheries Branch, was contacted to obtain construction costs for their Fairford fishway. The cost of the Denil ladder installed in 1984 was $110,000. The fish runs were constructed of treated wood with aluminum plate used for the weirs. Concrete construction would likely be higher cost. A cost estimate of $200,000 is probably reasonable for a 10-ft-high ladder serving the T and Y Diversion Dam. Estimated cost for a 5-ft-rise ladder is $120,000, (estimated as 60 percent of the 10-ft-rise ladder design).

<u>Bypass Channel Fishways</u> - Many of the fish species in the Tongue River move near the channel bottom. This behavior favors ramp-style drop designs as opposed to steep wall drops. For the low-height diversion dams of the Tongue River, multiple drop-type fishways could be constructed as bypass channels excavated around diversion dams. However, constructing bypass channels may require extensive placement of fill material due to the flat topography of the area. For example, the river banks upstream of the T and Y Diversion Dam were probably raised by levees when the dam was first constructed. Fill material would be required on the back side of levees for construction of a constant gradient bypass channel. Additional site reconnaissance of the four damsites is needed before a good assessment of the bypass channel alternative can be conducted.

Although not recommended due to insufficient site survey data, figure 13 gives a feasibility level view of a bypass fishway channel with multiple rock ramps. To maintain average fish pass velocities under 5 ft/s in a bypass channel, the average channel gradient should not exceed 0.01 ft/ft, the channel should be lined with a rock and cobble armor with a $D_{50}$ of 0.5 ft, and rock drop heights should not exceed 0.5 ft. The length of the bypass channel and number of rock ramp drops required are determined by the water surface differential created by a diversion dam.

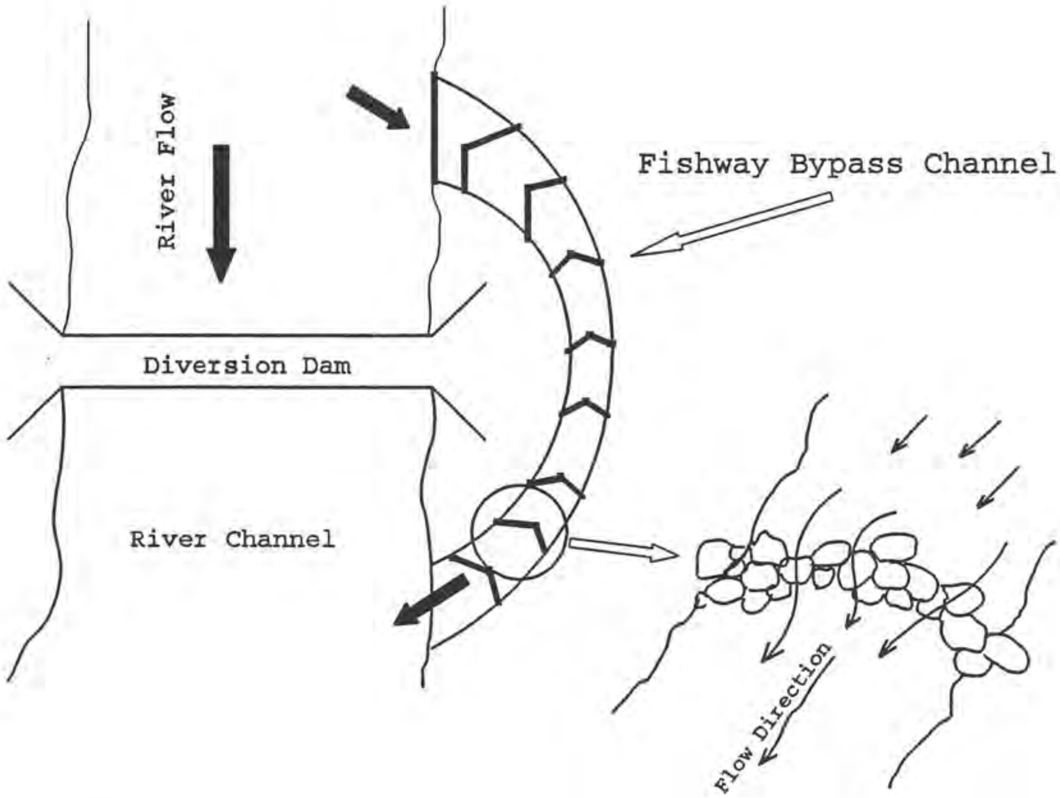



**Figure 13** - Fishway constructed as an excavated bypass channel with multiple rock ramp drops.

Stream Permits

The construction of any fishway in the river or along its banks will require several permits be obtained from State and Federal agencies. The following are standard permits required in Montana. Some permits may not be required depending on the construction activities employed. Other permits may be required based on locality.

- Montana Stream Protection Act (124 permit)
- Montana Floodplain and Floodway Management Act (Floodplain Development Permit)
- Short-term Exemption from Montana's Surface Water Quality Standard (3A Authorization)
- Montana Land-Use License or Easement on Navigable Waters
- Montana Water Use Act (Water Right Permit) - May be required for some fishways
- Montana Pollutant Discharge Elimination System (MPDES permit)
- Federal Clean Water Act (404 permit) River Hydraulics

## REVIEW OF APPROPRIATE TECHNOLOGY FOR SCREENING FISH FROM DIVERSIONS

### Selection Criteria

Primary objectives and selection criteria must be established prior to selection of screening technologies. By identifying objectives and criteria, viable alternatives can be limited and concept developments focused. Identified objectives and criteria include:

Species and Size of Fish to be Screened - Both appropriate through-screen velocities and appropriate screen materials (including opening size) depend on the size and swimming strength of the fish to be screened. Screen opening size and through-screen velocity criteria (both State and Federal - Table 7) have been established for salmon fry and fingerlings. Criteria for other species may be set through comparison to the salmon criteria. Screen designs for weaker swimming fish would thus be based on reduced velocities. Since diverted discharge or design screen capacity would be fixed, reduced through-screen design velocities will generate larger and more expensive screens and screen structures.

Table 7. Agency velocity criteria for screening salmonids. (Sources: EPRI 1986; K. Bates, Washington Department of Fisheries, personal communication.)

| Agency | Approach velocity (ft/s)[a] | | Transport velocity (ft/s)[d] |
|---|---|---|---|
| | Fry[b] | Fingerlings[c] | |
| National Marine Fisheries Service | $\leq$0.4 | $\leq$0.8 | Greater than approach velocity |
| California Department of Fish and Game | $\leq$0.33 for continuously cleaned screens: $\leq$0.825 for intermittently cleaned screens | Same as fry | At least twice the approach velocity |
| Oregon Department of Fish and Wildlife | $\leq$0.5 | $\leq$1.0 | Approach velocity or greater |
| Washington Department of Fisheries | $\leq$0.4 | $\leq$0.8 | Approach velocity or greater |
| Alaska Department of Fish and Game | $\leq$0.5 | Same as fry | No criterion |
| Idaho Department of Fish and Game | $\leq$0.5 | $\leq$0.5 | Sufficient to avoid physical injury to fish |
| Montana Department of Fish Wildlife and Parks | $\leq$0.5 | $\leq$1.0 | No criterion |

[a]Velocity component perpendicular to and approximately 3 inches in from the screen face.

[b]Fish less than 2.36-inches (60-mm) long.
[c]Fish 2.36-inches (60-mm) or longer.
[d]Theoretical velocity vector along and parallel to the screen face; also called sweeping velocity.

For the Tongue River, extremes in possible screen options would be to design screens to effectively retain stocked fingerling (2 inches or longer) smallmouth bass and channel catfish or design the screens to retain native species fry (2 inches or shorter). The fingerling smallmouth bass and channel catfish are fairly strong swimmers (estimate sustained swimming speed of 1.0 ft/s based on interpretations from Bell, Figure 14) while fry of native species are weak swimmers (estimate sturgeon fry sustained swimming speed of 0.3 ft/s based on Pavlov, 1989). An intermediate option would be to design for fry of smallmouth bass and channel catfish with an estimated sustained swimming speed of 0.5 ft/s.

Selection of the appropriate design species and size is based on interpretation of the fishery and the impact of losses in particular size or age groups. This is balanced against increased screen and screen maintenance costs associated with the more demanding criteria. Of course, the need to design for native species is tied to diversion dam passage. If the effort and expense are made to supply passage, then it would be appropriate to design screens to minimize the adverse impacts of the diversions on the restored fishery.

Velocity and Screen Opening Size Criteria - Although swimming performance of smallmouth bass and channel catfish are poorly known, based on interpretation of data presented by Bell (fig. 14) in conjunction with the screen velocity criteria (Table 7), it appears that for fingerlings a design normal component velocity of 0.6 ft/s would be appropriate. Likewise, for native species fry (noting that juvenile sturgeon will likely be weak swimmers) it appears that a design normal component velocity of 0.2 ft/s would be appropriate. The 0.2-ft/s design normal component velocity is currently being used for native species criteria in the Sacramento-San Joaquin Delta, California. For fry of smallmouth bass and channel catfish, an appropriate design normal component velocity would be 0.3 ft/s.

National Marine Fisheries Service (NMFS) criteria indicate that screen openings may be round, rectangular, square, or continuous slot. It is required that in the narrow direction screen openings will not exceed 0.125 inch for fry and 0.25 inch for fingerlings. NMFS also requires that the screen material supply a minimum 40 percent open area.

Screening Efficiency - The screen criteria described above will yield high-efficiency, positive barrier screens that effectively exclude nearly all fish (except for larvae and post-larvae) with little or no fish impingement on the screens. For fingerling and larger fish, louvers offer a less expensive screening option with potential screening efficiencies of 75 to 95 percent. Louvers are guidance structures which depend on

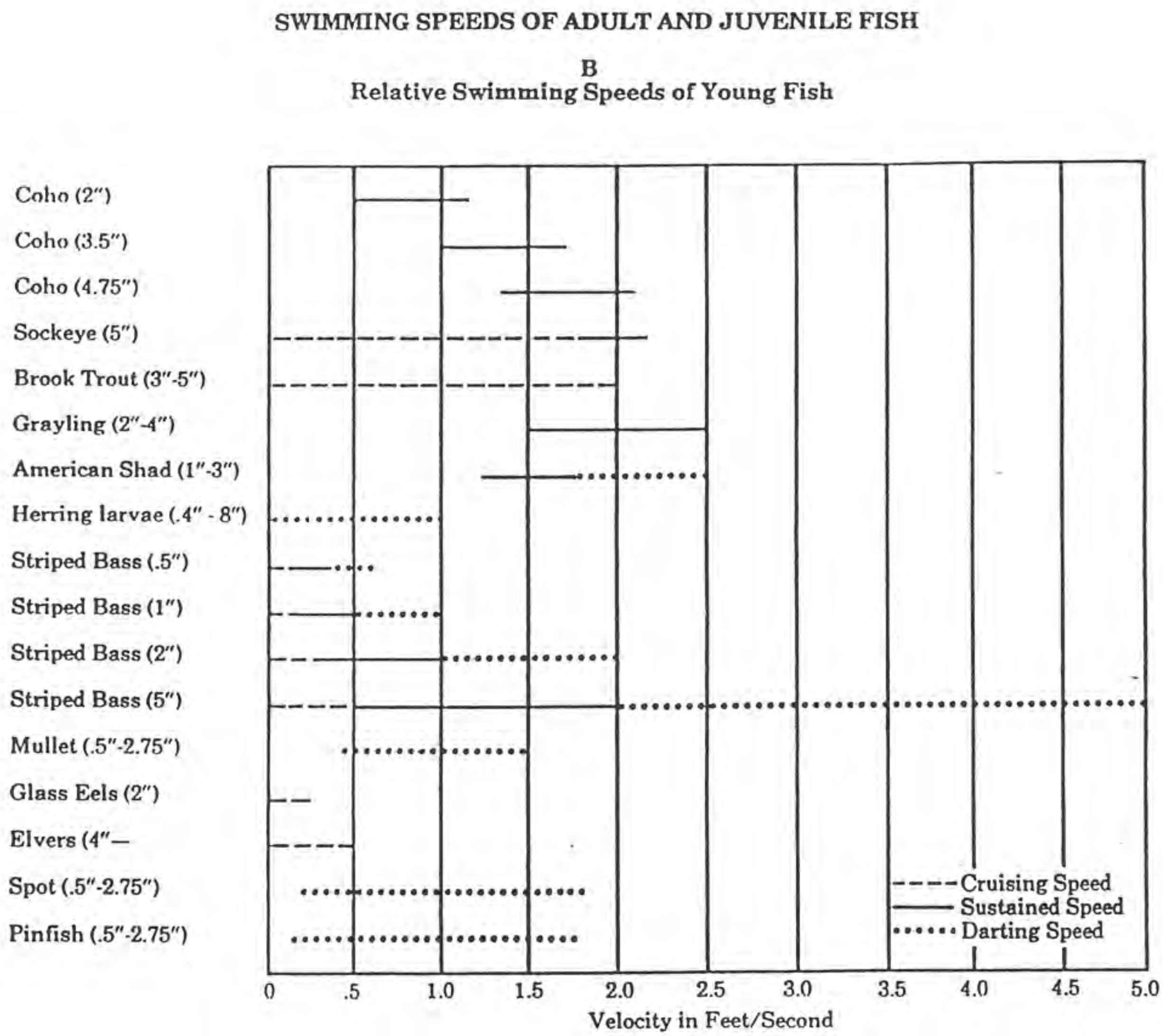



**Figure 14** - Relative swimming speeds of young fish (Bell, 1991).

behavioral response. As a consequence louver performance is species dependent. Louver efficiencies decline with smaller fish. Resource agency attitudes toward louvers vary widely across the country (discussed later in this chapter). However, depending on the fishery, louvers may be a viable option.

Currently, behavioral barriers (sonic and light barriers) are being actively studied at several locations around the country. These devices are attractive in that they offer low-cost, minimal structure options for fish exclusion. These devices are experimental, with performance potential not yet clearly documented. Studies do show that performance may be site- and species-specific and dependent on life stage and fish size.

Cost - With limited available funds and with many potential demands on those funds, the complexity, size and cost of recommended screen structures must be minimized. Costs of existing screen installations range from less than $1,000 to $10,000 per $ft^3/s$ screened. Every effort has been made to simplify design and minimize cost.

Operation and Maintenance - Recognizing the very limited operation and maintenance resources and manpower available, any screen structures developed must be basically demand free. This requires that screen concepts be largely self-cleaning; that sediment deposition at the screens be minimized; and, where mechanical or moving screens and equipment are used, required servicing will be nil.

Pumped vs. Gravity Diversion - A fish passage option is to replace gravity diversions, generated by the diversion dams, with pumped diversions. The diversion dams could then be removed. This is an option that is currently being explored by Reclamation for a 3,000-$ft^3/s$ diversion at Red Bluff, California. Although fish passage can be optimally improved, screening of the pumped flow is still required. Commercial screens are available that are well suited to pumped diversions. Cost associated with converting to a pumped diversion would include dam removal, construction and operation of the pumping plant, and capital and operating cost for the screens. Maintenance requirements likely also would increase. Development of a pump intake design that would be free of debris, ice load, and sediment problems would be difficult. Considering these factors, pumped diversions with associated screens were not further considered as an option in this study.

Electric Power - Depending on the screening concept, electric power may be required to drive screen cleaning equipment or to drive traveling or rotating screens. Water or paddle wheel driven screens are an option. Electric power is available near both the T and Y and S-H headworks. It is assumed that for limited demand, power would be available.

Winter Removal - Because of potential ice damage or ice fouling, winter screen removal is likely necessary.

Screening Alternatives - High Efficiency Screens

Two proven alternatives that can best meet the above criteria are drum screens and vertical stationary screens. In both cases, the screens would be configured to generate a sweeping flow which would guide fish downstream, off of the screens and into either a bypass or an exiting flow. Papers by Rainey and by Pearce and Lee discuss hydraulic objectives in detail, and present typical modern screen configurations. By guiding fish off the screen the sweeping flow minimizes fish exposure to the screen which reduces the potential of either fish impingement or entrainment. Sweeping flow also assists in moving sediment and debris downstream and off the screen thus reducing maintenance requirements.

Drum Screens - Drum screens are widely used to prevent fish entrainment into diverted irrigation flows. A typical angled drum screen structure consists of drum screens set end to end between piers (fig. 15). The front face of the piers is shaped to conform to the drums which minimizes blockage of fish guidance along the screen faces. The individual drums consist of rigid cylindrical frames covered by woven screen. The allowable size of openings in the screen is established by the previously discussed criteria (typically 3 to 6 mesh with 0.10- to 0.25-inch openings). Rubber seals that seat against the piers are attached to both ends of the drums. A bottom seal is fixed to the structure beneath the drum and seats against the drum surface. The drums rotate about their axis with a maximum outer circumference rotational speed of 10 ft/s. Typically, the drums are chain driven from electric motors located on top of the piers; however, paddle wheel drives are also available. The drums rotate so the front (upstream) face rises and the back face descends. The drums are operated 0.7 to 0.8 submerged. This submergence is required for proper debris handling. Typically, to maintain submergence within this limited range requires that the screens be installed in regulated (checked) canals. Debris that impinges on the screen is carried over the top by the rotation and washed off the backside by the through flow. This tends to be a very effective cleaning mechanism making drum screens a good self- cleaning design. If the submergence drops much below 0.7, debris tends to not cling to and carry over the drum, instead it accumulates along the front face. Trashracks should be included above the screen structure to prevent large debris loading. Drums have been constructed ranging from a few feet up to 20 feet in diameter and from the typical 10 to 12 feet in length up to 25 to 30 feet in length. Screen facilities have been constructed for discharges ranging from a few $ft^3/s$ to 3,200 $ft^3/s$. Facilities have been constructed which include from one up to 35 or 40 drums.

Bypass intakes are positioned at the downstream end of the screens and at intermediate positions, depending on structure length, velocities, and fish swimming strength (fig. 16). A thorough discussion of the design of bypass systems is presented by Rainey (1985). Bypass intakes function as velocity traps, intercepting and capturing the fish as they move along the screens and directing them to a conveyance that returns them to the river. On structures with multiple bypass intakes, the spacing

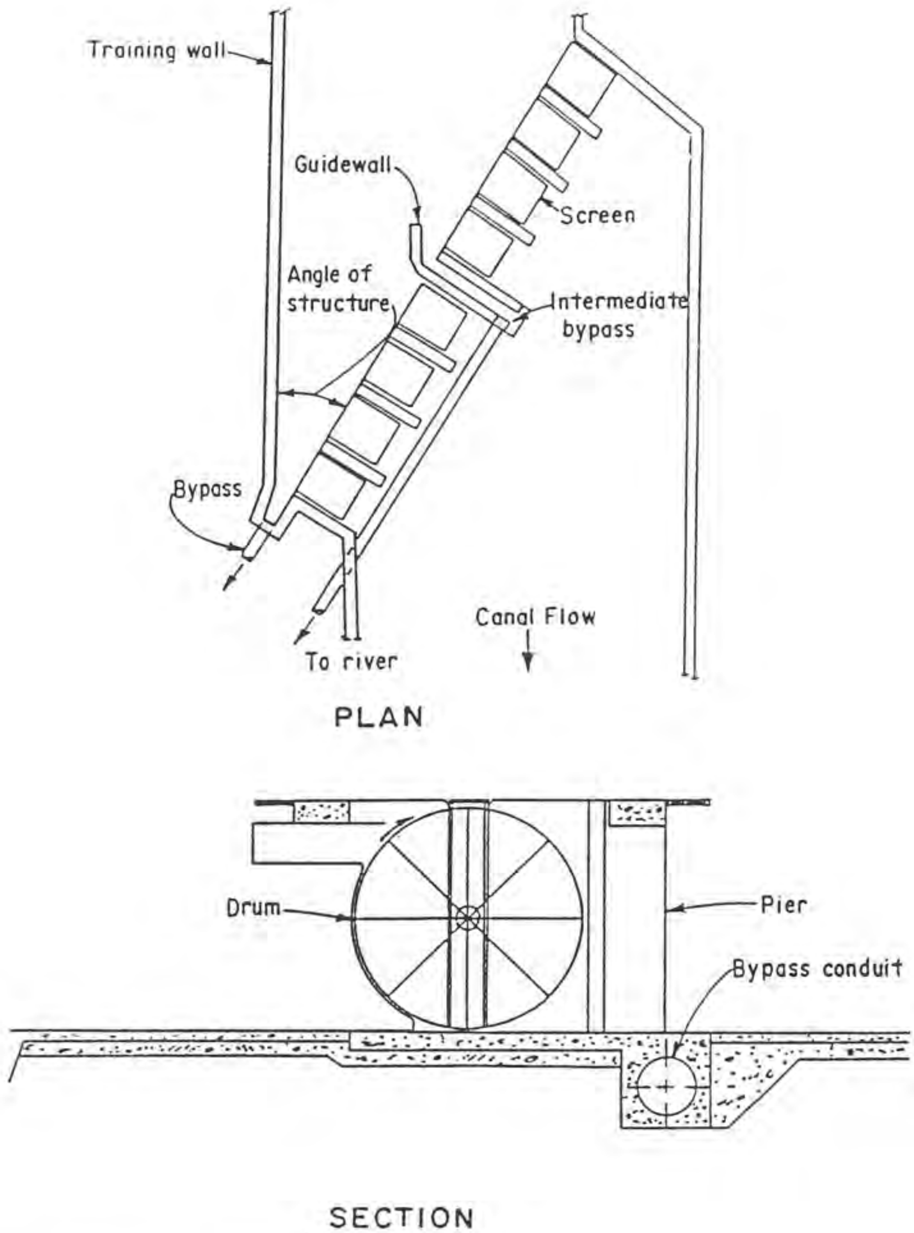



**Figure 15** - Schematic of typical drum screen.

between intake is dictated by the duration of time that fish can hold off of the screen and guide down the screen without impinging.

The bypass intake typically includes a guide wall, a vertical slot intake, an overflow weir gate and a downwell (fig. 16). The guide wall intercepts the fish and directs them into the vertical slot intake. The vertical slot intake runs the full depth of the water column so that the approaching fish do not have to change vertical position to enter. The required width of the slot varies (set by behavioral avoidance of narrow openings) but is often 1 to 2 feet. Required intake velocities also vary with fish swimming strength, but should be equal to or slightly greater than velocities in the screen approach channel. Typically intake velocities are 2 to 3 ft/s. It should be noted that the combination of slot width, slot height, and intake velocity yields a required bypass discharge. The overflow weir often includes a telescoping weir gate that allows desired intake velocities to be maintained with changing canal water surface elevation. It may be possible, with modifications, to achieve sediment sluicing or upstream fish passage through the bypass conduit.

For small gravity diversions, the Washington State Screen Shop in Yakima is fabricating modular, paddle wheel driven drum screens. Various 4-foot-long and 6-foot-long, single drum modules are available. Capacities range up to 4.3 $ft^3/s$. The modules offer a very cost-effective alternative for small diversions with installed cost of \$4,000 to \$5,000 per $ft^3/s$. The screen shop is actively supplying large numbers of screens to the states of Washington, Oregon, Idaho, and the Bonneville Power Administration.

Advantages:

1. Widely proven technology.
2. Good self-cleaning characteristics.
3. Positive barrier to fish entrainment.
4. Low, through-screen velocities which generate little or no fish impingement.

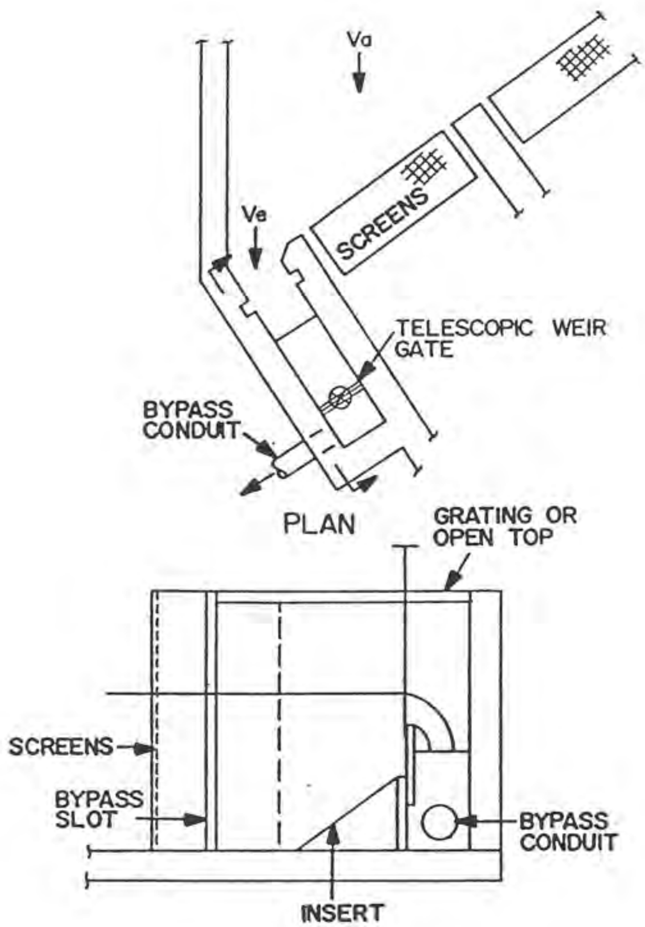



**Figure 16** - Bypass entrance and conveyance system (Rainey, 1985).

Disadvantages:

1. Rotating screens will require electric power or paddle wheel drive.
2. Seals and rotating machinery will require maintenance.
3. Cost of drum screen structures are high. Costs presented are summarized from the literature. Costs presented are for screens sized with a 0.5 or 0.4 ft/s normal component velocity. Screens sized with larger velocities would have lower unit costs and screens sized with lower velocities will have higher unit costs.

| Discharge | Unit cost in dollars |
| --- | --- |
| 80 to 250 $ft^3/s$ | \$4,400 to \$5,300 per $ft^3/s$ |
| 50 to 80 $ft^3/s$ | \$5,300 to \$6,500 per $ft^3/s$ |
| 15 to 50 $ft^3/s$ | \$6,500 to \$8,000 per $ft^3/s$ |
| 4.3 to 15 $ft^3/s$ | \$8,000 to \$10,000 per $ft^3/s$ |
| 2.0 to 4.3 $ft^3/s$ | \$4,000 to \$5,000 per $ft^3/s$ |

Angled Vertical Stationary Screens - Angled vertical stationary screens are a recently developed concept that functions much the same as angled drum screens. Basically, the drum screens are replaced by fixed or stationary vertically oriented screens (fig. 17). The screens may be oriented on a single continuous diagonal or may be arranged in a 'V' or multiple 'V' configuration to create a more compact structure. As with the angled drums, the angled stationary screens are oriented with the flow to generate low, through-screen velocities and to generate a downstream sweeping component which guides fish off the screens and into the bypasses. Velocity and screen opening size criteria are the same for the angled stationary screens as for the angled drums. Bypass designs and criteria are likewise the same for both structure types.

The big difference between the two concepts is the screen itself. Fixed, non-moving, flat plate screens replace the drums. Because of the simpler screen configuration, screen support pier sizes can be greatly reduced and the pier shapes simplified. Likewise, bypass intake geometry can also be simplified. Typically wedge-wire (or profile-wire) screen or perforated plate is used. Both wedge-wire screen and perforated plate present a very smooth screen face. For fixed screens, their cleaning characteristics are good. Nevertheless, the screens are fixed and will accumulate debris. Debris accumulation rates depend on debris load and type. Automated mechanical cleaners are often included. Cleaners used may include wipers, brushes, back sprays, and traveling arms that generate through screen eddies. A screen cleaner will be required, although a manual cleaning might be workable at the Tongue River sites. Paddle wheel driven cleaners might be developed.

Hydraulic and cleaning performance of the angled stationary screen is not dependent on the level of screen submergence. Consequently, the screen could be effectively installed either above or below the canal headworks. As with the drum screen structure, a trashrack should be included to prevent large debris loading on the screens.

Advantages:

1. Proven technology although not as widely used as drum screens.
2. Positive barrier to fish entrainment.

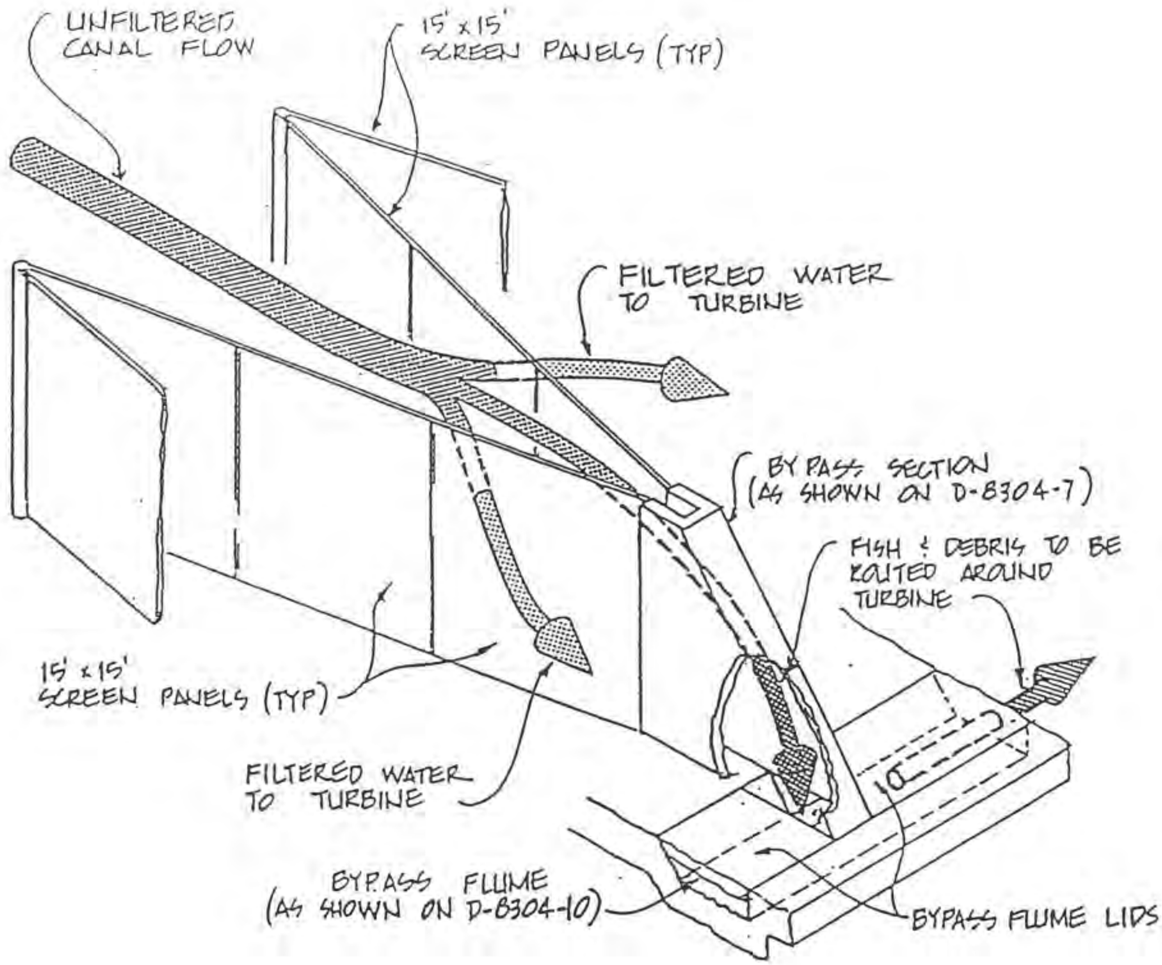



**Figure 17** - Angled vertical stationary screen (EPRI, 1994).

3. Low through screen velocities which generate little or no fish impingement.
4. Cost is one-third to one-fifth that of drum screen structures with costs ranging from \$800 to \$2,000 per $ft^3/s$ depending in part on screened discharge and normal component velocity criteria.
5. The screens do not move and consequently screen drives are not required and screen maintenance is minimal.

Disadvantages:

1. Self-cleaning characteristics of the screens are not as good as rotating drums.
2. Either a manual or automated cleaning system will be required. Manual systems will require operation at unknown frequencies (depends on debris type and load). Automated systems will require maintenance and either an electric or paddle wheel drive.

Screening Alternatives - Reduced Efficiency Option

Louvers - Louver structures are similar to the screen structures described above. However, the screens are replaced with a series of evenly spaced vertical slats. The slats or louvers are oriented at an angle to the flow which generates a sweeping or guiding flow to the bypasses (fig. 18). The louver system takes advantage of fish response to barrier generated turbulence. Louvers create hydraulic conditions which fish are able to detect and avoid. As fish move laterally away from the turbulence, they generally are moved downstream by the current and are directed into the bypass. Louvers are not positive barriers but depend on behavioral response for guidance. Guidance efficiencies (screening efficiencies) frequently are high (75 to 95 percent); however, effectiveness is more species-specific than with positive barrier screens.

The ability of fish barriers to guide is strongly influenced by the size, swimming ability, and behavioral response of the fish. Factors which affect louver performance include louver angle, approach velocity, bypass entrance velocities, louver slat spacing, fish species, and fish size. In some cases louvers have not performed to the satisfaction of the fisheries agencies. The NMFS, Northwest Region, takes the position that louvers typically do not provide adequate protection for juvenile salmon and steelhead. On the other hand, louvers are being actively pursued by the FWS in the Northeast and New England. Selection of louvers depends on analysis of the fishery, the species and sizes of fish present during diversion periods and their probable response to louvers. Judgement also needs to be made whether some losses are tolerable.

Louvers tend to function with higher flow velocities than positive barrier screens. As a consequence louver structures tend to be smaller and less expensive. As with trashracks, louvers will foul (with debris wrapping around the slats), in particular when loaded with filamentous plants. Although fouling can occur, open area through the louvers is large, as a consequence heavy fouling will reduce guidance efficiency but should not cause screen or canal overtopping. Again, trashracks should be used to prevent large debris loading.

Advantages:

1. Widely proven technology.
2. Continues to pass water when heavily fouled.

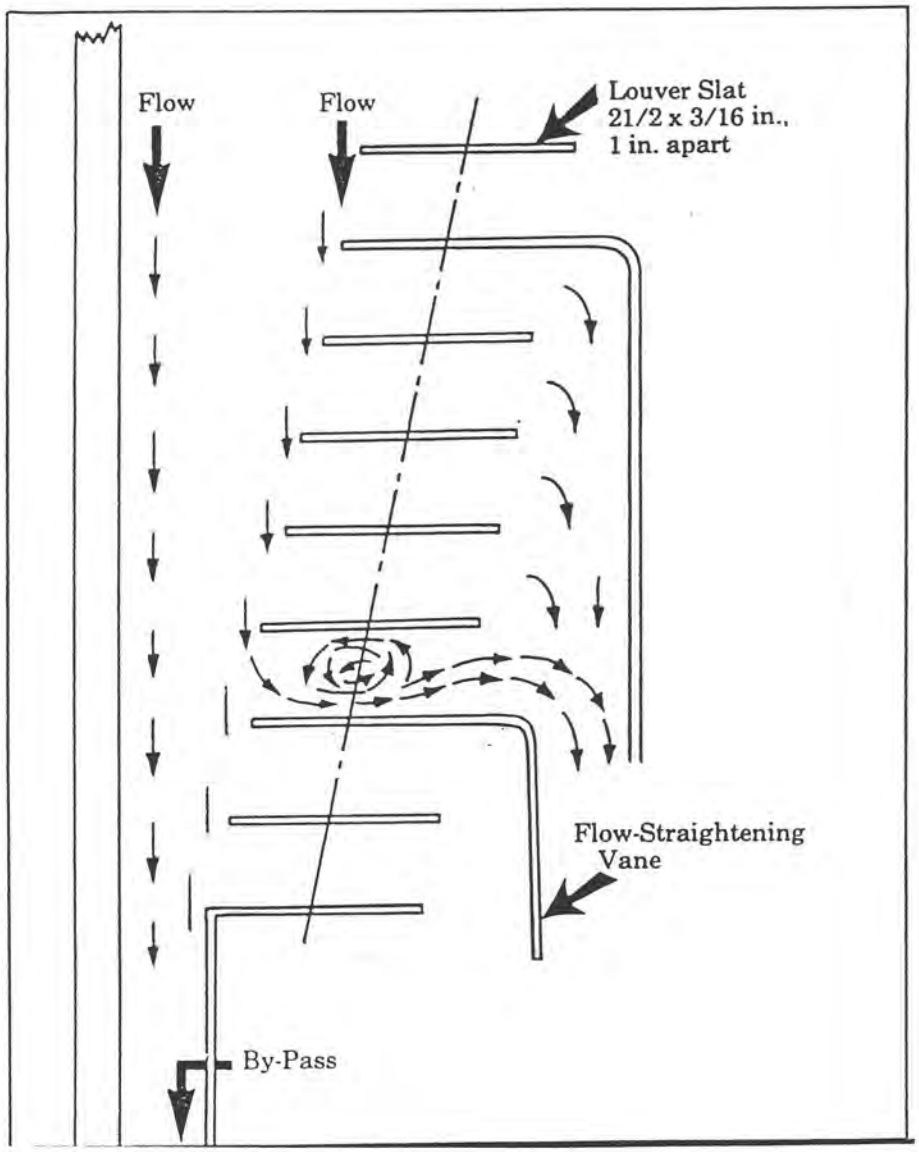



**Figure 18** - Flow past and through louver slats (Bell, 1991).

3. Approximately 30 percent less expensive than vertical stationary screens with unit costs ranging form \$600 to \$1,400 per $ft^3/s$ depending in part on screened discharge and velocity criteria.
4. Louvers do not move, consequently mechanical drives are not required.

Disadvantages:

1. Louvers are not positive barriers, consequently fish losses will occur (larvae and fry losses may be high).
2. Louvers will foul and manual or mechanical cleaning will be required.

## OPTIONS FOR FISH SCREENS AT THE TONGUE RIVER DIVERSIONS

The most appropriate screen or louver structures for the Tongue River diversions are similar in design. A typical design (fig. 19) includes the screen or louver array set at a flat angle to the flow to reduce through-screen velocities and maintain sweeping flow to the bypasses, the bypass entrance (or multiple entrances if intermediate bypasses are required), and the bypass conduit which returns the screened fish to the river. The structure which supports the screens or louvers would also support a working deck that runs the length of the structure. The screens are typically set in an enlarged reach of canal. Approach and exit channel cross sections are sized to maintain desired velocities. Possible auxiliary equipment includes power or paddle wheel drives for rotating drums, cleaning equipment (possibly automated), and hoists which would be used both for winter screen removal and general screen maintenance. If necessary, a downstream check structure should be added to maintain appropriate water depths at the screen.

Screen/louver facilities can be sited above the canal headworks; however, typically at this location space is not available, control of operating water surface elevation at the screens is lost, and debris loading is a greater problem. As a consequence, screens and louvers are usually installed on the canal below the headworks. The screens should be installed in a reach of canal which establishes uniform, will directed approach flow. With good approach flow distribution, good through-screen velocity distribution can be easily established. Beyond velocity considerations, the screens should be installed where space is available, excavation is minimized, and where the length of the bypass conduit can be minimized.

The size (and thus cost) of the screen structures depends primarily on the discharge that is being screened and the through-screen (normal component) velocity criteria that is used. Larger flows require larger and more expensive screens. If screens are designed to effectively handle fry or small, weak swimming, juvenile fish, through-screen or normal component velocities must be reduced. For a particular flowrate, reduced normal component velocities will yield larger screens. Selection of an appropriate normal component design velocity was previously discussed in the review of available screening technologies.

Screen costs were estimated for each of the diversion sites as a function of screen type (drums, vertical stationary, or louvers) and normal component velocity criteria. Estimates were based on existing screen costs published in the literature and/or determined through a Reclamation survey. Typically, available screen costs are presented as a function of screen type and total flow. In general, the referenced screens were designed for normal component velocities of 0.4 or 0.5 ft/s (a standard design criteria around the country). Adjustments in

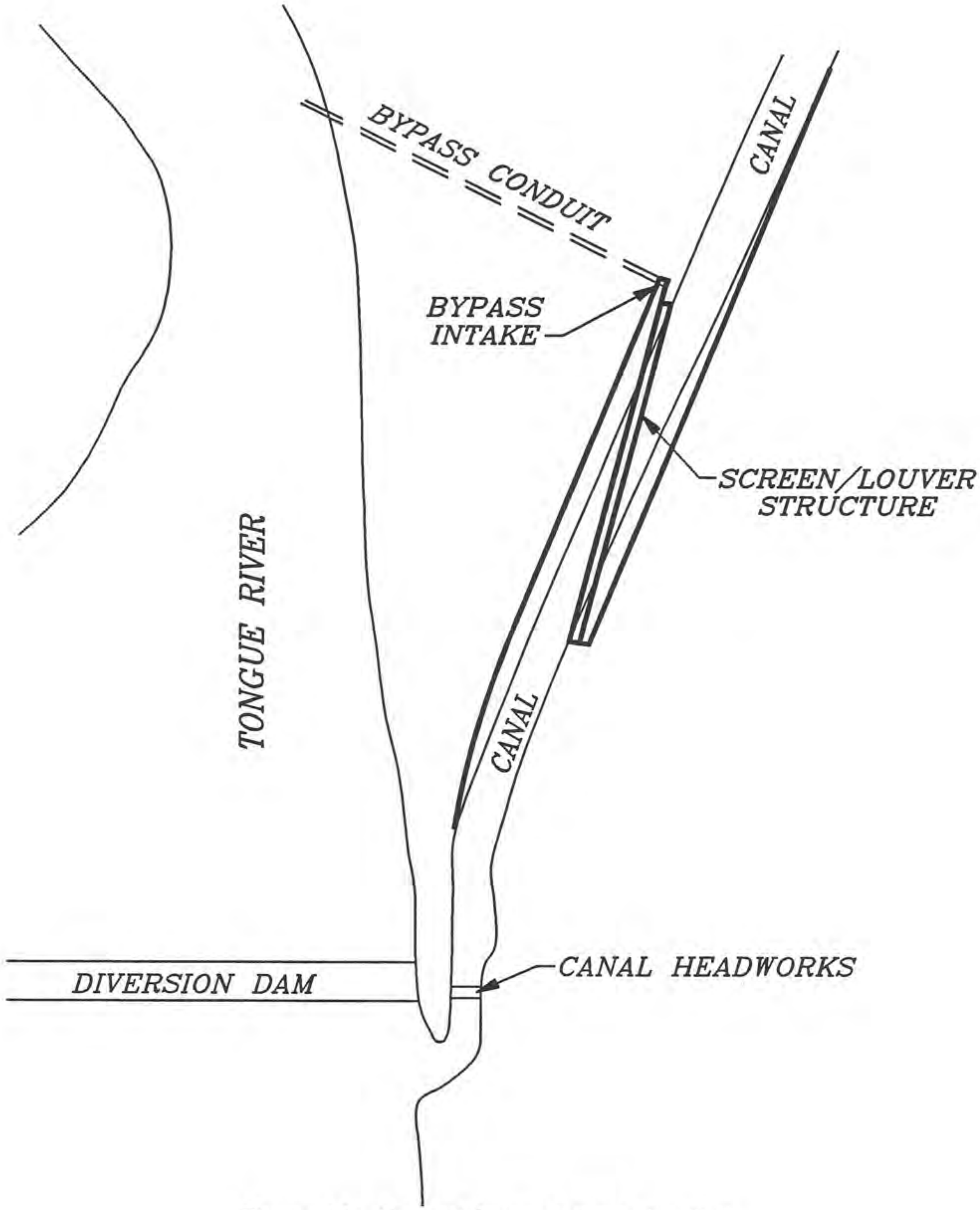



Figure 19 - Typical Screen/Louver Facility.

unit costs (cost per $ft^3/s$ screened) as a function of normal component velocity were estimated and included in the following table. Estimated costs of alternative screens are summarized below.

Table 8. Estimated Costs of Alternative Screens

| Screen Type | Normal Velocity | T & Y 220 $ft^3/s$ | SH 62 $ft^3/s$ | Mobley's 29 $ft^3/s$ | Brewester's 3.2 $ft^3/s$ |
|---|---|---|---|---|---|
| Drum | 0.2 | $2,000K | $620K | $350K | $30K |
| | 0.3 | $1,400K | $480K | $270K | $20K |
| | 0.6 | $970K | $330K | $190K | $15K |
| Fixed Vertical | 0.2 | $550K | $300K | $120K | $25K |
| | 0.3 | $350K | $130K | $90K | $20K |
| | 0.6 | $230K | $90K | $60K | $15K |
| Louvers | 2.5 ft/s approach | $200K | $75K | $50K | $15K |

Balanced against the above capital costs are operating costs. Although not clearly defined, and dependent on normal component velocity, debris type, and debris load, maintenance demands for cleaning vary substantially with screen type. Under moderately heavy debris loads, louvers will require at least daily cleaning. Louvers are configured much like trashracks and consequently cleaning is basically a racking operation (either manual or power). The fixed vertical screens, under moderately heavy debris load, may require hourly or even continuous cleaning. Numerous alternatives including wipers, brushes, back sprays, and traveling arms that generate through-screen eddies may be used on fixed vertical screens. Automated cleaners are frequently used. The drum screens, on the other hand, typically have very good self-cleaning characteristics even under moderately heavy debris loads. Cleaning maintenance on drums should be nil. An example is Reclamation's experience at Red Bluff, California. When constructed in the late 1960's, the Tehama-Colusa Canal headworks included a louver system. In late summer macrophyte growth in the Sacramento River loaded the louvers to the point that cleaning was required twice a day. In 1989 the louvers were replaced with an angled drum screen. With the drum screens, no special cleaning is required during the macrophyte season. The Tehama-Colusa drums were designed for a normal component velocity of 0.5 ft/s; however, typically the facility is operated at a maximum 50 to 60 percent of capacity.

For a particular screen concept, the extent of the cleaning problem is largely dependent on debris load and debris type. If typical debris loads are light during the irrigation season, louver systems could function with minimal cleaning requirements. Again at Red Bluff, Reclamation experience shows that in the early summer when macrophyte loads were light, very little louver cleaning maintenance was required. The fixed vertical screens, on the other hand, will probably always require at least limited cleaning. Fairly simple, continuously operating, mechanical cleaners are widely used.

For mechanical equipment associated with the rotating drums, lubrication of moving parts and periodic replacement of worn parts will be required. Periodically, in the off-season, seals will require replacement. The literature indicates that typically drum screen installations operate without major operation and maintenance problems. Mechanical cleaning equipment associated with fixed vertical screens is a recent development. However, approximately 80 fixed vertical screen facilities are in place (largely in California), that typically use continuously operating brush cleaning systems. The cleaning systems have been developed to the point that they are a low maintenance item. It can, however, be assumed that lubrication and periodic repair will be required.

Although screens (in particular drums and louvers) often operate with moderate sediment passage, incorporating a sediment sluice with the fish screen bypass or constructing a sediment trap and sluice above the screen likely would reduce screen maintenance requirements. Details of a sediment sluice design have not been addressed and costs have not been included in the presented estimates. It is anticipated that sluice options are not high cost items.

## SUMMARY

Unsafe spillway conditions and other associated safety problems at the Tongue River Dam on the Tongue River, Montana, has led to the "Tongue River Dam Rehabilitation Project." Construction may begin in 1996 to replace the spillway, improve the outlet works, and raise the reservoir's maximum water level 4 feet. U. S. Fish and Wildlife mitigation and enhancement features are being considered for both the reservoir and portions of the Tongue River below the Tongue River Dam. This report focuses on the river below Tongue River Dam and addresses both fish passage and fish protective measures that may be considered for the four small irrigation dams that presently operate to provide gravity-fed water for agriculture. The diversion dams, while providing stable amounts of irrigation water, function to block movements and migrations of riverine fish, and entrainment of downstream-moving fish into canals may be enough to limit present populations of both sportfish and native non-sport species. Of special significance is the T and Y Diversion Dam, located approximately 20 miles above the confluence of the Tongue and Yellowstone Rivers, and the first dam to present a fish passage barrier to native species migrating up from the Yellowstone River.

Some 35 species of fish, comprised of both native and non-native species, have been identified from the study area. Important native species apparently confined to river reaches below the T and Y Diversion Dam include burbot, paddlefish, shovelnose sturgeon, blue sucker, goldeye, and sturgeon chub. Sauger, though collected below and above the T and Y Diversion Dam, is impeded during spring spawning runs. Habitat for the rare pallid sturgeon is thought to exist both above and below T and Y dam. Non-native species of highest concern include smallmouth bass and channel catfish, which are managed for sportfishing.

Limitations of present knowledge regarding effectiveness of fish passage facilities for non-salmonid species have stymied passage programs throughout the United States, especially in the west. However, with native species on a steep decline attributable at least partly to blockage of movements and migrations by thousands of diversion dams throughout the west, regulatory agency and public interest in future fish passage initiatives is growing rapidly. Knowledge of fish protective measures at water intakes is more advanced, although most of the thousands of irrigation canal inlets throughout the west remained un-screened, or without any barrier to minimize fish entrainment and loss. Similar to fish passage issues, interest is growing rapidly for programs to provide protection from canal entrainment of fish.

All four diversion dams are small overflow weirs operated as run-of-river structures, providing no usable storage. Flow conditions below typical overflow dams are explained and related to fish passage issues. Following a review of the literature on swimming speeds of Tongue River species, and incorporating estimates of flow velocities and patterns below the dams, passage flow criteria were estimated as follows:

- Desired passage velocity = 2.0 ft/s; and,
- Maximum passage velocity = 4 ft/s for a maximum distance of 10 ft.

The importance of providing fish attraction and entrance flows is also emphasized. Several types of fish passage structures that may have application for the Tongue River were reviewed, including the "fish lift" or fish lock concept and Denil type ladders. Denil ladders in Canada demonstrated that adult walleye, sauger, white sucker and other resident species were effectively passed. A third type, a "sill type" fishway, which would provide a ramp-like feature incorporated into the bypass channel constructed around a diversion dam, is also explained but not considered at this time.

A "fish lift" concept using an air bladder with air compressor for a lift hinge is described for possible installation. Estimated cost for constructing a 10-ft-wide , 10-ft-high fish lift for the T and Y Diversion Dam is $78,000. Cost for a 5-ft-high lift, which may be applicable for the smaller diversion dams on the Tongue River, would be approximately $47,000.

A second fish passage option using a Denil, or "slot-type," ladder is also described. Based on Canadian studies, a ladder designed at a 12 percent grade requires run lengths of about 42 feet for a 5-foot elevation, and 84 feet for a 10-foot rise. Run lengths could be shortened using multiple runs with connecting resting pools. A cost estimate for construction of a 10-ft-high ladder would be about $200,000; for a 5-ft-high ladder, about $120,000.

Summaries of existing knowledge on technology for screening or diverting fish from water diversions is provided. Selection criteria are described considering the following: species and size of fish to be screened; velocity and screen size openings; screening efficiency; costs; operation and maintenance; pumped vs. gravity diversion; electric power needs; and winter removal requirements. Advantages and disadvantages are described for screens and barriers grouped into two general categories: "high efficiency screens" (i.e., rotating drum and vertical stationary screens); and "reduced efficiency options" (i.e., louvers).

Installation of screens or barriers with bypasses should be possible for all diversion dams on the Tongue River, if desired. High efficiency types are generally more costly, and are often placed where minimizing downstream migrating smolt salmon entrainment into canals is high priority. Louver type installations can provide good protection at lower costs, although debris cleaning requirements are often extensive. However, modern automated screen cleaning technology has alleviated much of the debris cleaning problem. Screening costs generally increase with amount of flow to be screened, small face velocity criteria, and smaller sized fish to be protected. Cost estimates for screening the canal inlets at all four diversion dams are provided, considering a range of face velocities and different screen types. At the T and Y Diversion Dam, installation costs could range from about $200,000 for louvers with 2.5 ft/s approach velocities to $2,000,000 for drum screens with 0.2 ft/s face velocity criteria ($970,000 with 0.6 ft/s face velocity). Fixed vertical screen installation costs would be somewhere in the middle, ranging \$550,000 for 0.2 ft/s face velocity to \$230,000 for 0.6 ft/s face velocity. All costs for the remaining three diversion dams would be less because of reduced total flows through canal headworks.

The state of the art regarding non-salmonid fish passage around diversion dams is best described as "experimental." Similarly, though less so, the state of the art for irrigation canal fish screening of non-salmonids is also quite experimental. Nevertheless, enough technology and information exists to generally guide an initiative for the Tongue River, provided that critical evaluations would follow any installation. Much remains to be learned regarding non-salmonid fish behavior near diversion dams and passageways; opportunities provided to particular fish populations through provision of passageways; extent of fish protection provided for various sizes of downstream migrating fish; and much more. Prior to installing fish passages or screens, more focused site-specific biological information would be needed, also. In general, a valuable opportunity appears possible for a program for the Tongue River that could potentially benefit local fishery resources while at the same time advance the state of the art to assist future western fish passage programs associated with irrigation diversion systems.

ADDENDUM

Fish passage considerations for Cartersville Diversion Dam on the Yellowstone River near Forsyth, Montana.

Cartersville Diversion Dam

Cartersville Diversion Dam spans the Yellowstone River near the town of Forsyth, Montana. The diversion dam was built in 1934. The dam is described as a submerged dam constructed of pile, rock, brush and concrete, figure 20. The headgate is constructed of concrete located on the north end of the dam. Portions of the dam have been washed out and repaired on several occasions since 1934. The dam is roughly 5-feet high with a steep downstream face. All flow passes over the top of the dam. Water is diverted from the Yellowstone River into a natural slough for about 2.25 miles and then into a constructed canal that extends easterly along the north side of the Yellowstone River for about 21 miles. The Cartersville Irrigation District holds a water right claim of 101.58 $ft^3/s$. The period of diversion is from April 1 to October 15 each year. The diversion is unscreened.

The dam is a barrier to native species of the Yellowstone River under most flows. The Montana Department of Fish, Wildlife and Parks has found the population of sauger upstream of the dam is only about 10 percent to 15 percent of that immediately downstream. Similarly, 1978 and 1979 fish surveys found no shovelnose sturgeon above the diversion dam (Penkal, 1981). Fish passage at the site is needed that will provide passage for the many fish species that historically migrated past the site, including shovelnose and pallid sturgeon.

**Figure 20** - Photograph of Cartersville Diversion Dam, 1994.

Sturgeon passage likely represents the greatest fish passage challenge at Cartersville Dam. There is little precedence to guide design of sturgeon passage structures. The best information on sturgeon passage is from observations of white sturgeon on the lower Columbia River. White sturgeon have been documented passing Bonneville, The Dalles, John Day, McNary and Priest Rapids Dams. These dams have fish ladders and a few fish locks designed primarily for use by salmon and steelhead. Use of these fishways by sturgeon has been highly variable and generally very limited (Warren and Beckman, 1991). At Bonneville Dam during the years 1938 to 1956 sturgeon were observed passing through both fish ladders and fish locks.

The original fishway ladder baffles at Bonneville Dam contained only weirs without bottom orifices. This design prevented all but a few sturgeon from negotiating the ladders. In 1950 the baffles were modified to include bottom passage orifices. Bottom orifices were added to improve salmon passage; however, sturgeon passage also benefited. Although sturgeon passage through the fishway ladders increased following installation of bottom orifices, sturgeon ladder passage remained small compared to fish lock passage, figure 21. During the period that both fish ladders and fish locks were operated at Bonneville Dam, the fish locks accounted for about 97 percent of white sturgeon passage. The fish locks were operated until 1956 and then only intermittently until 1971 when they were abandoned.

Currently, the ladders in use on the lower Columbia River are generally overflow weir types with bottom orifices. The east ladder at The Dalles Dam has shown the highest use by white sturgeon, passing an average of about 500 sturgeon each year between 1986 and 1991. Sturgeon passage on the east ladder is nearly 10 times that of other similar ladders on the lower Columbia system. The reason for the higher use of the east ladder at The Dalles is unknown. Fish ladders on the lower Columbia River dams are similar in design with baffles ranging from 24 to 30 feet in width and 6 ft in height. Baffles are between 10 to 16 feet apart with a minimum of 1 foot of water surface elevation drop across each baffle. Bottom orifices range from 18 inches to 24 inches square. The 1-foot water surface drop across the weirs produces an average velocity of about 8 ft/s. Following the addition of bottom orifices, sturgeon observed passing through the ladders have moved almost totally by way of the bottom orifices.

Two pairs of fish locks were operated at Bonneville Dam prior to 1956. The locks were 20 feet square and provided 90 feet of vertical lift. The locks had a bottom fish crowder to move fish out of the locks when filled with water. The success of the locks also varied, apparently due largely to attraction conditions. Ivan Donaldson, the fish lock operator, for many years recorded that sturgeon passage dropped sharply when swifter than normal flows from the fish collection facility occurred. Sturgeon also showed a preference for deep entrances to passage facilities. Surveys of fishermen below Bonneville Dam have revealed sturgeon are rarely taken in flows less than 12-feet deep. However in contrast, sturgeon have been observed displaying considerable swimming strength as demonstrated by their use (although limited) of the Columbia River fish ladders. Another example is observations of white sturgeon jumping above the water surface below Bonneville Dam following spillway

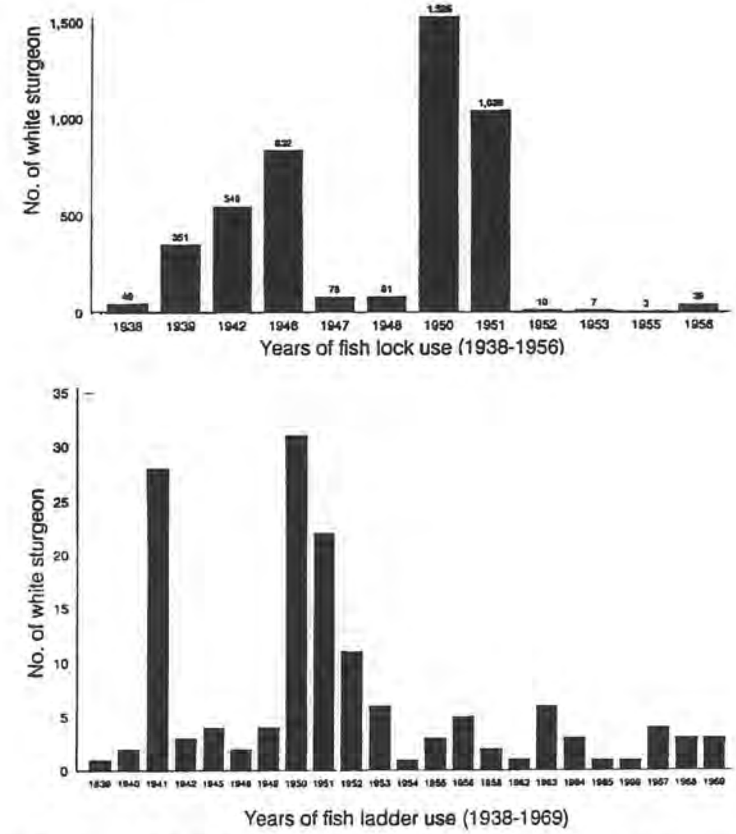



**Figure 21** - Historical use of fish locks and fish ladders by white sturgeon at Bonneville Dam, U.S. Fish and Wildlife Service.

gate operation. White sturgeon have also been observed spawning in gravel beds under flows of 3- to 6-feet depths and velocities up to 10 ft/s. Of similar note are the findings of fish surveys on the lower Yellowstone (Backes and Gardner, 1994) which found shovelnose sturgeon were more abundant in areas of fast to moderate currents overlying gravel beds.

Factors like flow level, turbidity and temperature have been shown to be triggers that induce the spawning migration of many of the fish species found in the Yellowstone River. The most important factor that must be considered in relation to fish passage is flow level. Penkal (1981) estimates flows in the Yellowstone River below the intake diversion dam must exceed about 15,000 $ft^3/s$ to stimulate paddlefish spawning migration. Similarly, Zakharyan (1972) found a strong dependency on river flow for shovelnose sturgeon spawning in the Tongue River. Spawning movement of sturgeon, sauger, and paddlefish typically start with rising spring flows in late April and May, peaking in coincidence with flow in June and early July. However, ripe spawning sturgeon have been found in the river into early August after flows have dropped well below peak levels.

Several basic objectives for fish passage at Cartersville Diversion Dam can be identified from the many fish studies of the Yellowstone River. These are:

- Fish passage must accommodate a number of warm water species including sturgeon.
- Fish ladder concepts must include bottom passage of sufficient size to pass fish of up to 1000-mm in length.
- Maximum passage flow velocities should not exceed 3 to 4 ft/s.
- The passage structure should be located near the south river bank to avoid direct entrainment into the canal.
- The structure must provide attraction flows that can be easily field adjusted.
- The approach to the fish passage structure should be deep and extend into the river thalweg below the dam.
- Passage concepts must be operable under the wide range of river flows encountered during spring and summer spawning period. (A water surface profile for the river reach near Cartersville is needed to identify the head drop across the dam as a function of river flow.)
- Passage concepts need to be low maintenance. Designs should emphasize methods that pass trash and debris.

Fishway Ladder Concepts

The fish passage objectives identified for Cartersville Dam could be achieved with a low gradient weir and orifice or vertical slot type ladder design. In order to limit average flow velocities across baffles to 3- to 4-ft/s range, the elevation drop across each baffle cannot exceed about 0.33 ft. The shape and orientation of the baffle passages are also very important to fish orientation and efficient movement through the ladder. In addition, fish behavioral aspects must be considered. Some fish migrate largely during daylight, using predominantly visual referencing. In this case, baffle openings must be large enough that they do not create an avoidance response. Fish that migrate largely at night or during periods of high turbidity often rely on rheotactile stimulus, sensing the changes in flow by their lateral line. In this case, controlling flow turbulence levels within ladder pools is very important.

Baffle passage size, pool length and passage alignment are important to achieving desired flow conditions. Often rectangular shaped passages are desirable, whether slots or orifices. The smallest dimension of the passage opening must be sufficient to easily allow passage of the largest expected fish. However, this dimension should also be minimized to achieve maximum decay of orifice or slot flow velocity within the length of the downstream pool. A pool length between baffles of at least 10 slot widths is desirable. A pool length of 10 slot (or orifice) widths produces about 30 percent decay of the maximum orifice or slot jet velocity. Alignment of the passage openings from baffle to baffle is also important. Alignment influences energy dissipation and flow patterns established within each pool. Laboratory studies conducted by Katopodis, figure 22, demonstrate how changing alignment can create both desirable and undesirable flow patterns. Ladders designed with the passages aligned from baffle to baffle typically result in low turbulence and high passage velocities.

Offsetting baffle passages cause more of the high-velocity flow to impact the downstream baffle wall, therefore, resulting in stronger circulation and greater energy dissipation within each pool. Strong turbulence levels or strong eddies within pools can cause fish disorientation and result in poor passage efficiency. The ladder geometry must be adjusted to balance flow passage velocity and turbulence level objectives.

Much more information about the structure, river stages, channel geometry upstream and downstream of the structure and the fishery (if available) is needed before a concept level design could be pursued. However, for concept purposes, one can assume a fishway ladder for Cartersville Diversion Dam would be approximately as follows. Assuming a maximum of 5 feet of drop over the dam, the ladder would require about 15 baffles to limit passage velocities to desired levels. Baffles with bottom passage openings (orifice or vertical slots) of between 0.75 foot and 1 foot should be considered to start. Pool lengths of about 7.5 to 10 feet will be required. With 15 pools, the length of fishway ladder required is between 112 feet and 150 feet. Ladder width and depth are normally a function of desired fish passage capacity. For the objectives of the Cartersville fish passage project, ladder width and depth will likely be guided by fish (sturgeon) behavior. Based simply on observations of white sturgeon passage on the Columbia River, maintaining a depth of 5 feet or more in the attraction channel and ladder pools between baffles is desirable. Designing a ladder for sturgeon passage requires maximum flexibility of design and function. Baffles should be made so they are removable and baffle passages are field adjustable (to the degree possible).

Operation and Maintenance of Fish Ladders - A coarse trashrack would be required at the upstream entrance to the ladder to prevent large debris from entering the ladder. The trashrack would require periodic cleaning when heavy debris loads are present in the river. Cartersville Diversion Dam is a run-of-river dam and, therefore, subject to large changes in river stage each year. Operating a fish ladder over a wide range of river stages may require periodic adjustment of the ladder baffling to maintain target flow conditions.

## Fish Lock Concepts

Experience with white sturgeon on the lower Columbia River has shown fish locks to be well suited to sturgeon passage. In comparison to fish ladders, fish locks generally require greater operational costs and are less effective at passing large numbers of fish. However, the low structural height of Cartersville Diversion Dam and the objectives for fish passage on the Yellowstone River are quite different than those of most locks. The low structural height of the dam allows for many simplifications in the design that reduces construction, operation and maintenance costs. For example, the fish lock could be as simple as the overshot weir fish lock proposed for diversion dams on the Tongue River, figure 12. The fish lock would consist of guide walls constructed of concrete or sheetpile set over the existing dam near the south river bank. An overshot weir gate located near the downstream end would cycle to control flow and the passage of fish. A fish lock of this type has the advantages of good trash and debris passage, could operate over a wide range of river stage and would require only a small air compressor at the site to operate the weir gate. However, this design has

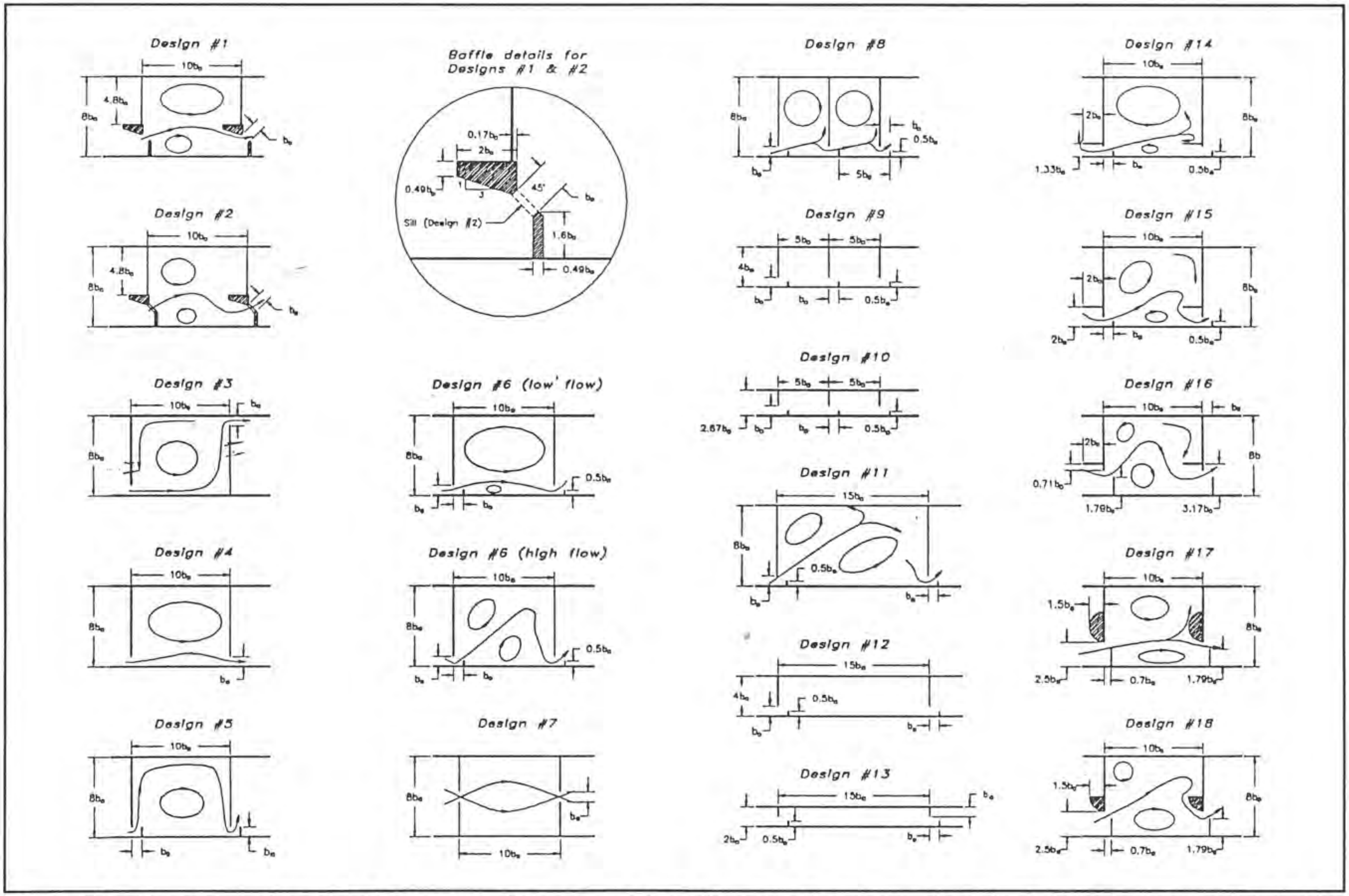



**Figure 22** - Examples of pool eddy patterns (plan view) for different alignments of vertical slot openings in fish ladder baffles, Katopodis, 1991.

not been field tested. Additional data on this type of passage structure should become available in 1996 through a Reclamation research program on fish passage for small diversion dams. Design of traditional style vertical fish locks should also be considered. The primary deterrent to traditional locks for the Cartersville Dam site is the level of complication and maintenance potentially required at an unmanned facility.

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